THE STATE OF CLIMATE CHANGE SCIENCE 2007

HEARINGS

BEFORE THE

COMMITTEE ON SCIENCE AND TECHNOLOGY

ONE HUNDRED TENTH CONGRESS

FIRST SESSION

February 8, April 17, and May 15, 2007

Serial Nos. 110–2, 110–20, and 110–30

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THE STATE OF CLIMATE CHANGE SCIENCE 2007: THE FINDINGS OF THE FOURTH ASSESSMENT REPORT BY THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC), WORKING GROUP I REPORT

THURSDAY, FEBRUARY 8, 2007

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE AND TECHNOLOGY,
Washington, DC.

The Committee met, pursuant to call, at 10:00 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Bart Gordon [Chairman of the Committee] presiding.

BART GORDON, TENNESSEE
CHAIRMAN

RALPH M. HALL, TEXAS
RANKING MEMBER

U.S. HOUSE OF REPRESENTATIVES

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Hearing on

"The State of Climate Change Science 2007: The Findings of the Fourth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC), Working Group I Report"

2318 Rayburn House Office Building
Washington, D.C.

Thursday, February 8, 2007
10:00 AM – 12:00

WITNESS LIST

Panel I

The Honorable Nancy Pelosi
Speaker of the House of Representatives

Panel II

Dr. Susan Solomon
Co-Chair, IPCC, Working Group I: *The Physical Basis of Climate Change*

Dr. Kevin Trenberth
Coordinating Lead Author, IPCC, Working Group I, Chapter 3: *Observations: Surface and Atmospheric Climate Change*

Dr. Richard Alley
Lead Author, IPCC, Working Group I, Chapter 4: *Observations: Changes in Snow, Ice and Frozen Ground*

Dr. Gerald Meehl
Coordinating Lead Author, IPCC, Working Group I, Chapter 10: *Global Climate Projections*

HEARING CHARTER

COMMITTEE ON SCIENCE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

The State of Climate Change Science 2007: The Findings of the Fourth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC), Working Group I Report

THURSDAY, FEBRUARY 8, 2007
10:00 A.M.–12:00 P.M.
2318 RAYBURN HOUSE OFFICE BUILDING

Purpose

On February 8, 2007, the Committee on Science and Technology will hold a hearing on the first section of the 2007 Assessment Report, *Climate Change 2007: The Physical Science Basis of Climate Change,* prepared by Working Group I of the Intergovernmental Panel on Climate Change (IPCC). Released in Paris, France, on February 2, 2007, this document presents a comprehensive appraisal of the current state of scientific knowledge of climate change.

The Committee will hear testimony from four witnesses who were involved in the preparation of the Working Group I Report. The witnesses will present the findings of the Report and discuss the relationship between the current findings and those of past IPCC reports on the state of climate change science.

Key Findings of the 2007 Working Group I Report

On February 2, 2007 the Intergovernmental Panel on Climate Change (IPCC) released the first section of its Fourth Assessment Report, entitled "The Physical Science Basis of Climate Change."

This first section of the IPCC Fourth Assessment Report builds upon information contained in the previous reports. It updates information from the Third Assessment Report based upon research conducted over the past six years. Uncertainties in some areas have been reduced (e.g., quantitative estimates of radiative forcing). Climate models have improved, and expanded observations, data and information have enabled the IPCC to increase the level of confidence in some earlier findings (e.g., attribution of warming to human-induced increases in greenhouse gas concentrations). In other areas (e.g., changes in frequency of tropical cyclones) uncertainties remain and further research is needed to determine what patterns, if any, exist.

Despite remaining uncertainties, the Fourth Assessment Report represents a significant expansion in our knowledge of the influence of human activity on the Earth's climate. It is almost 30 years since the first international scientific conference on climate suggested that human activity could be impacting the Earth's climate. This report confirms the original suspicions raised by scientists participating in the 1979 climate conference as has every report of the IPCC from the first report in 1990 to the present.

The 10 key findings in the 2007 report are:

- Atmospheric concentrations of greenhouse gases have increased significantly due to human activities since 1750 due to fossil fuel use and land-use change.
- Our understanding of human-induced influences on climate has improved since the 2001 Assessment. There is now very high confidence that Earth is warming.
- Evidence that Earth is warmer includes: increase in global average air temperature and ocean temperature, widespread melting of snow and ice, and rising global average sea level.
- Long-term changes in climate have been observed including: changes in Arctic temperatures and ice, changes in the amounts of precipitation, ocean salinity,

and wind patterns and changes in extreme weather events such as droughts, heavy precipitation, heat waves, and intensity of hurricanes and typhoons.

- Changes in diurnal temperature ranges, Antarctic sea ice extent, meridional overturning circulation of the global ocean, and localized extreme weather events such as tornadoes, lightning, and dust storms have not been observed.
- The interpretation that the warming of the last 50 years is unusual in at least the previous 1,300 years is consistent with paleoclimate information. During the last period when polar regions were significantly warmer than present for an extended period of time (about 125,000 years ago), reduced volume of polar ice led to sea level rise of four to six meters.
- Most of the observed increase in globally averaged temperatures since the mid-twentieth century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations. Discernible human influences now extend to other aspects of climate, including ocean warming, continental-average temperatures, temperature extremes and wind patterns.
- Analysis of climate models coupled with constraints of observations enables an assessed likely range to be given for climate sensitivity for the first time and provides increased confidence in the understanding of the climate system response to radiative forcing. The likely global average surface warming associated with a doubling of CO_2 concentration is in the range 2 to 4.5°C. It is very unlikely that climate changes of at least the seven centuries prior to 1950 were due to variability generated within the climate system alone.
- For the next 20 years a warming of 0.2°C per decade is projected for a range of emission scenarios. Even if the concentrations of all greenhouse gases and aerosols had been kept constant at year 2000 levels, a further warming of about 0.1°C per decade would be expected.
- Continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system during the twenty-first century that would very likely be larger than those observed during the twentieth century.

Background

Prior to the establishment of the IPCC, the World Meteorological Organization (WMO) convened two international meetings on greenhouse gas emissions and global climate. In 1979, the first World Climate Conference issued the following concern: "continued expansion of man's activities on Earth may cause significant extended regional and even global changes in climate." In 1985 the United Nations Environment Program (UNEP), WMO, and the International Council for Science (ICSU) organized a joint conference on the "Assessment of the Role of Carbon Dioxide and of Other Greenhouse Gases in Climate Variations and Associated Impacts." This conference concluded that "as a result of the increasing greenhouse gases it is now believed that in the first half of the next century (twenty-first century) a rise of global mean temperature could occur which is greater than in any man's history."

In response to the findings of these earlier conferences, the IPCC was created by WMO and UNEP in 1988. The IPCC was created to provide assessments of scientific, technical and socio-economic information relevant to understanding the risk of human-induced climate change, its potential impacts and options for adaptation and mitigation.

The IPCC is organized into a Plenary which meets once a year and is attended by officials and experts from relevant ministries, agencies, and research institutions from member countries and from participating organizations. This body makes the decisions about preparation of new reports, their scope and content, and accepts reports prepared by expert teams. It elects the IPCC Chair, currently Rajendra K. Pachauri, and the members of the IPCC Bureau. It also establishes IPCC principles and procedures, designs the work plan and budget for the Panel and its activities. The IPCC Secretariat is located in Geneva, Switzerland.

The IPCC relies upon primarily peer reviewed, published scientific and technical literature. The IPCC also prepares special reports and technical papers on topics where independent scientific information and advice is deemed necessary. The panel operates within extensive peer review and governmental review, thus ensuring a high level of transparency, scientific credibility, and policy relevance. Hundreds of experts from around the world contribute to the assessment reports as authors, contributors, and reviewers. Participants are selected by the members of the IPCC Bureau (30 members each from a different nation) who are all elected for five to six years and who are all experts in climate change. Participants may be nominated by governments or participating organizations or they may be chosen due to their recognized expertise.

The IPCC published the First Assessment Report in 1990, Supplementary Reports in 1992, a Special Report in 1994, a Second Assessment Report (SAR) in 1995, and a Third Assessment Report (TAR) in 2001. Each of the assessment reports are comprised of three volumes from three corresponding working groups (I, II and III).

First Assessment Report

The First IPCC Assessment Report was completed in 1990 and provided policymakers with a comprehensive assessment of what was then known, and not known, about human influence on climate. The report provided the main scientific basis for the negotiation of the Framework Convention on Climate Change (UNFCCC). The 1992 United Nations Framework Convention on Climate Change was ratified by the United States and called for a "non-binding," voluntary goal for industrialized countries to stabilize their emissions of greenhouse gases at 1990 levels by the year 2000.

The 1990 IPCC report, as well as two Supplementary Reports (1992 and 1994) supplied critical information for the United Nations Conference on Environment and Development in Rio de Janeiro in June 1992. The Convention went into effect in March 1994 and the first session of the Conference of the Parties (COP) was held in Berlin in April 1995.

In the 1990 assessment, the authors' wrote, "The size of the warming is broadly consistent with predictions of climate models, . . .but the unequivocal detection of the enhanced greenhouse effect from observations is not likely for a decade or more." The report projected an increase in average global temperature during the twenty-first century of 0.3 degrees Celsius per decade and discussed the possible consequences of that temperature change in relation to rising sea levels, increase in extreme weather events, and serious pressure on aquatic and terrestrial ecosystems.

Second Assessment Report

Completed in 1995, the Second IPCC Assessment Report expanded on the findings of the 1990 assessment. The Second Assessment Report stated that the climate of the Earth had changed over the past century, increasing the global mean surface air temperature somewhere between 0.3 and 0.6 degrees Celsius. The report stated that climate was expected to change further in the future and projected an increase of 1.0 to 3.5 degrees Celsius by 2100.

In the 1995 report, the IPCC concluded that ". . .the balance of evidence suggests that there is a discernible human influence on global climate." This second assessment provided key input to the negotiations that led to the adoption of the Kyoto Protocol in 1997. More than 160 nations, parties to the Framework Convention on Climate Change, adopted the Kyoto Protocol, with legally binding obligations to limit emissions of industrialized nations for the years 2008 to 2012. The Protocol's emissions targets are hailed as important first steps toward the Framework Convention's objective of avoiding dangerous climate change.

Third Assessment Report

The Third Assessment Report, "Climate Change 2001" consisted of three working group reports on "The Scientific Basis," "Impacts, Adaptation and Vulnerability," and "Mitigation." The findings also contained a synthesis report, which addressed a range of policy relevant scientific and technical questions. This third report emphasized the findings from the previous five years and projected that average global temperature would rise from 1.4 to 5.8 degrees Celsius over the next century. In addition, authors explained how precipitation patterns are expected to change, the degree to which sea level is expected to rise, and the possibility of the increases in extreme weather events.

By the release of the 2001 report, confidence in the ability of models to project future climate increased and authors concluded, "There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities." Furthermore, extensive and wide-spread evidence is present demonstrating that the Earth is warming and clear signals of a changing climate exist.

Witnesses

Dr. Susan Solomon of the National Oceanic and Atmospheric Administration (NOAA):

Dr. Susan Solomon serves as Co-Chair of Working Group I of the Intergovernmental Panel on Climate Change (IPCC), providing scientific information to the United Nations Framework Convention on Climate Change. Her current research includes climate change and ozone depletion, and she served as an overall coordinator for the report. After receiving her Ph.D. in chemistry from the University of California at Berkeley in l98l, she has been employed by the National Oceanic and Atmospheric Administration as a research scientist. Her scientific papers have provided not only key measurements but also theoretical understanding regarding ozone destruction, especially the role of surface chemistry.

Dr. Solomon will provide an overview of the key findings of the report. Working Group I's contribution to the Fourth Assessment Report includes 11 chapters. Each chapter has two Coordinating Lead Authors who are responsible for pulling together the material for the chapter. In addition to the Coordinating Lead Authors, there are a number of Lead Authors as well as numerous contributors and reviewers associated with each chapter.

Each of the other IPCC authors, Dr. Trenberth, Dr. Alley, and Dr. Meehl will discuss the findings with a focus on their respective chapters.

Dr. Kevin Trenberth of the National Center for Atmospheric Research (NCAR):

Dr. Kevin Trenberth served as a Coordinating Lead Author for Chapter 3 of the report entitled: *Observations: Surface and Atmospheric Climate Change.* Currently, Dr. Trenberth is Head of the Climate Analysis Section at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado. From New Zealand, he completed his undergraduate degree in mathematics at the University of Canterbury, Christchurch, New Zealand, and obtained his Sc.D. in meteorology in 1972 from Massachusetts Institute of Technology, Cambridge, Massachusetts.

Dr. Richard Alley of the Department of Geosciences, Pennsylvania State University:

Dr. Richard Alley served as a Lead Author for Chapter 4 of the report entitled: *Observations: Changes in Snow, Ice, and Frozen Ground.* Dr. Alley is Evan Pugh Professor of Geosciences and Associate of the Earth and Environmental Systems Institute at The Pennsylvania State University, University Park, where he has worked since 1988. He received his Ph.D. in 1987 from the University of Wisconsin–Madison and his M.Sc. (1983) and B.Sc. (1980) degrees from The Ohio State University–Columbus, all in Geology. Dr. Alley teaches, and conducts research on the climatic records, flow behavior, and sedimentary deposits of large ice sheets, to aid in prediction of future changes in climate and sea level.

Dr. Gerald Meehl of the National Center for Atmospheric Research (NCAR):

Dr. Meehl is a Coordinating Lead Author for Chapter 10 of the report: *Global Climate Projections.* Dr. Meehl received his Ph.D. in Climate Dynamics from the University of Colorado in 1987. His expertise is in the field of climate modeling. He has been a scientist on staff at NCAR since 1979. He has been a member of the Working Group I Report Group since 1989 and has participated in the development of previous IPCC assessment reports.

Definitions:

Radiative forcing—an external disturbance in the radiative energy budget of Earth's climate system brought about by changes in atmospheric concentrations of greenhouse gases, changes in solar radiation, or changes in the surface reflective properties of Earth.

Meridional overturning circulation—the circulation system of the world's oceans driven by variations in temperature and salinity. Cold, dense water formed in polar oceans sinks and is replaced by warmer, less dense surface water from temperate latitudes.

Chairman GORDON. Well, good morning, and welcome to this hearing on the Intergovernmental Panel on Climate Change, or IPCC, Report on the current state of our knowledge on climate change.

This is the first opportunity Congress has to examine the findings of this important report.

The first warnings about the potential for climate change came in 1979 when the first international conference on climate change expressed the concern that human activity might lead to significant regional and global changes in climate.

Now, almost 30 years later, increasing evidence confirms this warning is real.

The importance of this report cannot be overstated. The Report provides overwhelming evidence that global warming is real and that human activity is the driving force.

The Report's findings may be alarming, but it is not the work of alarmists. The Report's findings were endorsed unanimously by the representatives of 113 nations, including the United States, and it is the product of the work of nearly 300 scientists. In short, this is a unanimous, definitive statement that global warming is real and it is very likely that humans have contributed to it.

And let me just make that clear. This is a unanimous, definitive statement. That meant that every nation, every scientist had to agree to that. And so the Nation that might be the most naysaying, the scientists that might be the most skeptical still had to agree to this Report. So, at a minimum, this is a conservative report about climate change.

The scientific experts have provided us with a diagnosis of the problem and a prognosis for our nation's health. If we continue along our current path, the prognosis is ominous.

The scientists have done their job. Now, it is time for us, the policy-makers, to do ours.

We face a big challenge. We must explore ways to reduce emissions, to adapt to coming changes, and to mitigate the negative effects of climate change. We cannot accomplish all this overnight, but we must begin in earnest now to address this serious issue. And with some bit of irony, today, the Science Committee has a bill of mine on the Floor in about an hour that will be the first bill that will address renewable energy. We hope it will be—we don't hope, we know it will be the first of many bills.

The IPCC Report tells us that if we fail to act, our children, my five-year old daughter, Dana's triplets, Brian's twins, and Madame Speaker, your little four-month-old son, or grandson—you look wonderful—they are all going to be affected, and they are going to live in a very different world. And let me just say, this is not hypothetical. When you start talking about 10 years, 20 years, 50 years, maybe 100 years, it seems like it is a long time off, but the actuaries tell us that our children are all going to live to the end of this century. And certainly, our grandchildren are going to live beyond that. So this is real. This is not hypothetical. We are talking about something that is going to affect all of us in a very personal way, because they are going to inherit a world which has much more severe droughts in some regions, greater flooding in others, and very different coastlines due to a higher sea level.

And two days ago, my daughter spent the afternoon in my office. We were looking out at the Capitol and I am hoping that when she is older she is going to remember that view.

And I don't want to look in my daughter's eyes in 10 or 20 years and try to explain why I didn't take advantage of the opportunity to address global warming while I was in Congress.

We need to improve existing technologies and to develop new technologies and to reduce emissions and to make our economy and our society more energy efficient. And we must understand the impacts of climate change on our ecosystems that support all life on Earth.

Continued scientific research is imperative. We need better, more refined regional assessments to understand the climatic vulnerabilities of communities, ecosystems, and our economy. We must continue to gather information on greenhouse gas emissions and the Earth's response to them and to further expand our understanding of climate and weather.

These four eminent scientists are a select few representing the efforts of thousands of scientists from all over the world. And as I said earlier, they have done their job. They have set the scientific information before us. We must now move forward and act upon this information.

We, on the Science and Technology Committee, can and must play a role by ensuring that the science and research continue to provide us the information we need to understand climate change and to respond to it.

However, we must also begin with the information and tools in hand today to adapt to the changing climate and to buy ourselves time to adapt and to innovate by reducing emissions and energy use.

We are world leaders in science and innovation. I intend for this committee to ensure we maintain that leadership and lead the world to address it with us.

On behalf of the Committee, I want to thank all of our witnesses for joining us today and for the work you have done in preparing this paper.

[The prepared statement of Chairman Gordon follows:]

PREPARED STATEMENT OF CHAIRMAN BART GORDON

Good morning and welcome to this hearing on the Intergovernmental Panel on Climate Change (IPCC) report on the current state of our knowledge on climate change.

This is the first opportunity Congress has to examine the findings of this important report.

The first warning about the potential for climate change came in 1979 when the first international conference on climate change expressed the concern that human activity might lead to significant regional and global changes in climate.

Now, almost 30 years later increasing evidence confirms this warning is real.

The importance of this report cannot be overstated.

The Report provides overwhelming evidence that global warming is real and that human activity is driving this change.

The Report's findings may be alarming, but it is not the work of alarmists.

The Report's findings were endorsed unanimously by the representatives of 113 countries, including the United States.

And is the product of the work of nearly 600 scientists.

In short, it is a unanimous, definitive statement that global warming is real and that it is very likely humans have contributed to it.

The scientific experts have provided us with a diagnosis of the problem and a prognosis for our planet's health. If we continue along our current path, the prognosis is ominous.

The scientists have done their job. Now, it is time for us—the policy-makers—to do ours.

We face a big challenge. We must explore ways to reduce emissions, to adapt to coming changes, and to mitigate the negative effects of a changing climate.

We cannot accomplish all this overnight, but we must begin in earnest now to address this serious issue.

The IPCC Report tells us that, if we fail to act, our children—my five-year-old daughter, Dana's triplets, and Brian's twins—will live in a much different world.

A world with more severe droughts in some regions and greater flooding in others. And much different coastlines due to a higher sea level.

Two days ago, my daughter spent the afternoon with me in my office. We were looking out at the Capitol and I am hoping that when she is older, she will remember that view.

I don't want to look in my daughter's eyes in 10 or 20 years and try to explain why I didn't take advantage of an opportunity to address global warming while I was in Congress.

We need to improve existing technologies and to develop new technologies to reduce emissions and make our economy and society more energy efficient.

And we must understand the impacts of climate change on the ecosystems that support all life on Earth.

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However, we must also begin with the information and tools in hand today to adapt to the changing climate and to buy ourselves time to adapt and innovate by reducing emissions and energy use.

We are world leaders in science and innovation. I intend to ensure this committee works to ensure we maintain that leadership. I believe we can meet this challenge and we can, and should, lead the world to address it with us.

On behalf of the Committee, I want to thank all of our witnesses for agreeing to come before us this morning. I believe most of you have just returned from the meeting in Paris. We appreciate the work you have done and your willingness to appear today.

Chairman GORDON. And at this time, I will recognize our very distinguished Ranking Member, Mr. Hall, for an opening statement.

Mr. HALL. Good morning. And I thank you, and I thank the Chairman for organizing this hearing about the very important topic of global warming, or as some prefer to call it, climate change.

Let me start by thanking all of the witnesses for being here today. This will be a key issue in the 110th Congress, and I hope that I speak for all of the Committee Members in saying that we appreciate the time that you all give us. Madame Speaker, we appreciate your appearing before us. I was amazed at the crowds outside there. At my age, I was fearful that someone had discovered I might have been one of the Lindbergh kidnappers. I didn't know what everybody was doing there. But you are all welcome. I see Sherry Boehlert, our former Chairman, in attendance, a great leader and a man that gave much of his time to this committee, and to this Congress, and to this nation. Thank you, Sherry.

There will be a lot of debate in this Congress about what policies the United States should adopt to deal with the potential impacts of climate change. While today's hearing is focused primarily on the latest science related to climate change, it also is a public forum, and I expect Members will stray from the science and offer their opinions on various policy options that have been proposed.

So in that vein, let me set the record straight from the beginning. I am skeptical about mandatory regulation of greenhouse gases, which some of my colleagues are promoting as the best solution to the problem of climate change.

As a nation, we can't figure out how to write a cap-and-trade bill that does not cause an immediate spike in natural gas prices, a spike that endures for several years at the very least. The result would be the closing of more factories, the closing of steel mills, paper mills, lumber mills, and many others. Gas price increases over the last six years, even without carbon regulation, have already caused millions of permanent layoffs. Factories won't compete with utilities to buy gas. Rather, they will move to China and India where there are no pollution controls, inevitably worsening global emissions. In the meantime, Americans will be paying the price.

Clearly, we need to make the American people fully aware of the cost of mandatory emission caps. The discussion of mandatory caps comes down to one question: what is the maximum cost to the U.S. economy in dollars per family in a global warming bill, and what is the minimum effect on world-wide temperatures our country is willing to accept at such cost?

Of course, in order to fully answer that question, we will need to factor into the equation the contribution, or lack of contribution, of those countries who produce much of the pollution problems and seem unwilling to be a part of the solution. I would like to see this committee address this important equation in the near future.

We have an historic opportunity to use American innovation to help address the problem, and our committee is poised to offer competitive solutions. I would like to see more discussions on how technology, especially alternative energy technologies, can help address the issue of energy independence and climate change. I would also like to explore how we can encourage the development of technologies to use existing domestic resources more cleanly, effectively, and efficiently. In fact, later this morning, we will be considering an alternative energy technology bill on the House Floor. There is no limit to American innovation. When we put our minds to solving a problem, we find answers that not only benefit our country, but also the world. We have always been leaders in technology. This should be no exception. I would like to see this committee promote the development of a wide range of new technologies to help America become energy independent while maintaining our competitive edge in the world economy. In the end, innovation can do a lot, but only so much. World powers must absolutely do their part. Without this, there can be no true success in solving the problem of global warming.

I look forward to hearing from our witnesses today and yield back my time.

[The prepared statement of Mr. Hall follows:]

PREPARED STATEMENT OF REPRESENTATIVE RALPH M. HALL

Good morning. I am glad the Chairman organized this hearing about the important topic of global warming, or as some prefer to call it, climate change. Let me start by thanking all of the witnesses for being here today. This will be a key issue in the 110th Congress and I hope I speak for all the Committee Members in saying we appreciate your time and the expertise that you can provide to our discussions.

There will be much debate this Congress about what policies the United States should adopt to deal with the potential impacts of climate change. While today's hearing is focused primarily on the latest science related to climate change, it is also a public forum and I expect Members will stray from the science and offer their own opinions on various policy options that have been proposed. So, in that vein, let me set the record straight from the beginning. I aim skeptical that mandatory regulation of greenhouse gasses, which some of my colleagues are promoting, is the best solution to the problem of climate change.

As a nation, we can't figure out how to write a cap-and-trade bill that does not cause an immediate spike in natural gas prices—a spike that endures for several years at the very least. The result will be the closing of more factories—steel, paper, lumber and many others. Gas price increases over the last six years, even without carbon regulation, have already caused millions of permanent lay-offs. Factories won't compete with utilities to buy gas. Rather, they will move to China and India where there are no pollution controls, inevitably worsening global emissions. In the meantime, Americans will pay the price.

Clearly, we need to make the American people fully aware of the costs of mandatory emission caps. The discussion of mandatory caps comes down to one question—What is the maximum cost to the U.S. economy (in dollars per family) in a global warming bill, and what is the minimum effect on worldwide temperature our country is willing to accept at such cost? Of course, in order to fully answer that question, we will need to factor into the equation the contribution, or lack of contribution, of those countries who produce much of the pollution problems and seem unwilling to be a part of the solution. I would like to see this committee address this important equation in the near future.

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I look forward to hearing from our witnesses today and yield back the balance of my time.

Mr. SENSENBRENNER. Mr. Chairman, I have a parliamentary inquiry.

Chairman GORDON. The gentleman from Wisconsin.

Mr. SENSENBRENNER. My parliamentary inquiry, Mr. Chairman, is are all of the witnesses that will appear today, including the distinguished Speaker, going to be subjected to questioning under the five-minute rule, as required by House Rule 11?

Chairman GORDON. The gentleman raises a good question, but I will excuse the Speaker after her opening remarks.

Mr. SENSENBRENNER. A further parliamentary inquiry. Is the Chair aware that House Rule XI 2.(j)(2)(A) reads as follows: "Subject to subdivisions B and C, each Committee shall apply the five-minute rule during the questioning of witnesses and the hearing until such time as each Member of the Committee, who so desires, has had an opportunity to question each witness."

Chairman GORDON. I am aware of it, and I ask unanimous consent that the Speaker be allowed to leave after her opening statement.

Mr. SENSENBRENNER. Mr. Chairman, I object, and I request that House Rule 11, as cited, be applied, because it is mandatory.

Chairman GORDON. As the gentleman knows, anything can be waived by unanimous consent.

Mr. SENSENBRENNER. Mr. Chairman, I object.

Chairman GORDON. Well, if that is your choice, then you will be able to do that, and I am sure that the Speaker will give you a very good answer.

Thank you, Mr. Hall. And Sherry Boehlert, as you can see, things still don't always change around here, but we welcome you back. And you prove that you can come home, and that we are very glad you are here.

I ask unanimous consent that all additional opening statements submitted by the Committee Members be included in the record. Without objection, so ordered.

[The prepared statement by Mr. Costello follows:]

PREPARED STATEMENT OF REPRESENTATIVE JERRY F. COSTELLO

Good morning. I want to thank the witnesses for appearing before our committee to discuss the first section of the 2007 assessment report, *Climate Change 2007: The Physical Science Basis of Climate Change,* prepared by the Working Group I of the Intergovernmental Panel on Climate Change. This is a sobering report that demands our attention and I commend Chairman Gordon for moving quickly to hold today's hearing.

This report gives the Congress added momentum to take meaningful action to combat global warming, and I look forward to working with my colleagues as we craft such legislation. This process needs to be one of consensus, taking a wide view of our current energy realities as well as the goals we need to reach in the future. As the Working Group's report states, "continued greenhouse gas emissions at or above the current rates will cause further warming causing changes in the global climate system." Given the current state of scientific knowledge of climate change and prior reports based upon six years of research, we need to work together to find responsible solutions to take action to slow this trend.

Toward this end, we cannot ignore the reality that coal is going to play a role in our nation's energy supply and the world energy supply for years to come. Coal generates half of the electricity in this country and is a reliable domestic source of power with a 250-year supply of coal in the U.S. alone.

To fully maximize our use of coal, we must continue to take steps that reduce emissions. The only way to achieve this goal is through advancements in technology. I have been a strong supporter of clean coal initiatives and programs to advance the research and development needed to improve coal-based electricity generation. Congress must continue to support the clean coal programs in the President's FY08 budget, which includes the FutureGen Project, slated to be the world's first zero-emissions coal plant. Among other things, FutureGen will demonstrate the ability to sequester carbon dioxide emissions safely underground. The more coal plants using clean coal technology equals less harmful emissions in our atmosphere and a reduction of greenhouse gases.

Clean coal technologies do exist; however, they need the support and backing from Congress to further develop and demonstrate their commercial viability. As we consider climate change legislation, I encourage my colleagues to include coal as part of our energy solution. Again, I look forward to working with my colleagues as we find practical solutions that lead us down the path of energy independence and protection of our environment.

I welcome the panel of witnesses and look forward to their testimony.

[The prepared statement by Ms. Johnson follows:]

PREPARED STATEMENT OF REPRESENTATIVE EDDIE BERNICE JOHNSON

Thank you, Mr. Chairman. Today's hearing brings representatives of an important body of scientific knowledge on the state of science regarding climate change.

The Intergovernmental Panel on Climate Change (IPCC) has spent hundreds, maybe thousands of hours preparing this report. The Panel gathered the world's leading experts on Earth science and surveyed the literature.

The Panel took comments from the greater scientific community. All of this work has resulted in a high quality product that policy-makers should take seriously.

I have been frustrated by the lack of action—real action—in dealing with climate change from the legislative standpoint.

Why don't we mandate stricter standards to that all automobiles run on a greater number of miles per gallon of gasoline? Why haven't we passed into law good ideas such as the Chairman's on alternative fuel research and development?

Why haven't we explored and utilized more of our domestic oil resources in the short-term, while investing heavily in solar, wind, nuclear, hydrogen fuel research and development?

Why haven't we provided more incentives for the American people to buy fuel-efficient or hybrid vehicles?

The number of unanswered questions of this nature keeps growing.

I am eager to hear what today's witnesses have to say, and I thank the Chairman for inviting them to testify today.

[The prepared statement by Mr. Lipinski follows:]

PREPARED STATEMENT OF REPRESENTATIVE DANIEL LIPINSKI

I am pleased that with this hearing today, we will continue the discussion on the issue of global climate change in the House Committee on Science and Technology.

The science on climate change has come a long way since the first international scientific conference on climate almost 30 years ago. This fourth assessment report by the IPCC represents a significant expansion in our knowledge of the influence of human activity on the Earth's climate. The solid scientific conclusions reached in this report allow us to move beyond debating whether humans are affecting climate change, and let us begin the discussion of how to resolve the dilemma before us.

The challenges we face, which are documented in dramatic scientific detail within this report, highlight the need to act and act now. The need to find cleaner, less polluting sources of energy to reduce our impacts on climate change offers us a future of great opportunities, especially as we seek to compete in the global economy of the 21st Century.

Fortunately, feasible approaches to reducing carbon dioxide emissions are no longer out of reach. In the 109th Congress, the House Committee on Science heard from U.S. businesses that had implemented energy efficient practices and manufacturing changes to reduce greenhouse gas emissions. I applauded the voluntary actions of these businesses for taking the lead even in the absence of mandatory requirements.

This is a global challenge, and we must do our part to see that the health of our planet does not deteriorate further. As such, we must work on providing greater incentives to all U.S. businesses so they will continue to develop new environmentally friendly technologies and implement further reductions in greenhouse gas emissions.

I look forward to the release of the Working Group II and Working Group III reports later this spring and welcome the chance to learn how we might go about mitigating global climate change. It is my hope that creative and vigorous dialogue in the 110th Congress will yield concrete results that will put us on the right path toward a more sustainable future.

[The prepared statement by Mr. Ross follows:]

PREPARED STATEMENT OF REPRESENTATIVE MIKE ROSS

I would like to first thank Chairman Gordon and Ranking Member Hall for holding today's hearing on climate change. I would also like to thank Speaker Pelosi for coming before the Committee today and all of the witnesses who have come here to discuss their findings on this topic.

I am honored that our committee will be the first to hear from the authors of the Intergovernmental Panel on Climate Change's Report on Global Climate Change.

I strongly believe that our nation must develop a comprehensive plan that combats climate change by investing in alternative and renewable fuels and reducing greenhouse gas emissions and I am hopeful that today's hearing will continue the discussion of climate change to aid in this process. I also believe in a common sense approach to imposing regulations that will help to improve our environment and combat the harmful effects of global warming, while maintaining jobs and strengthening our nation's economy.

I am hopeful that all of these goals can be met and I look forward to today's discussion of the IPCC's report, which will provide great insight into this topic.

[The prepared statement by Mr. Carnahan follows:]

PREPARED STATEMENT OF REPRESENTATIVE RUSS CARNAHAN

Mr. Chairman, thank you for placing this important hearing first on the calendar of the Committee on Science and Technology for the 110th Congress. By prioritizing it on our agenda, you have helped to emphasize the growing importance of climate change on the national debate.

Speaker Pelosi, it is a tremendous honor to have you appear before us today and I look forward to hearing your testimony on the state of climate change. Your presence speaks loudly to your commitment to bipartisan action on this very important issue. Thank you for joining us.

The conclusions of the Intergovernmental Panel on Climate Change (IPCC) have clarified that human-induced influences impact the climate. With very high confidence, the IPCC now tells us that the Earth is warming as is indicated by an increase in global average air and ocean temperature, widespread melting of snow and ice, and rising global average sea level. While this news is unfortunate, the certainty with which science now warns that human actions are impacting the climate should motivate the Congress to move forward on legislative solutions.

I am proud to say that last Congress I was very active on the issue of global warming, introducing a bipartisan and bicameral Sense of Congress resolution, H.Con.Res. 453, aimed at addressing global warming through the negotiation of international treaties. Furthermore, during debate on the 2005 Energy bill, I attempted to amend the bill by redrafting and extending the Hybrid tax credit, a credit that was eventually enacted into law and is a step forward in our efforts to stem harmful emissions.

St. Louis has one of the highest rates of asthma and respiratory diseases in the country, the causes of which are directly related to global warming. For this reason, climate change is an issue of vital importance to my constituents.

I look forward to hearing the testimony of Speaker Pelosi and the IPCC witnesses and participating in the conversation of climate change as we deliberate over legislative solutions in the 110th Congress. Thank you all for being here today.

[The prepared statement by Mr. Mitchell follows:]

PREPARED STATEMENT OF REPRESENTATIVE HARRY E. MITCHELL

Thank you, Mr. Chairman.

I think one of the things the American people are hoping from this Congress is for Democrats and Republicans to work together to take the threat of global warming to our environment and our national security seriously.

We are watching our planet rapidly change before our eyes. Once majestic ice caps are melting. Weather patterns are changing in very troubling ways. The temperature of our atmosphere is on the rise. The intensity of rains and drought are more extreme. Hurricanes, such as Katrina, are becoming more powerful, and more deadly.

The scientific evidence that global warming exists—and that humans are largely responsible for the change in our climate—is overwhelming.

The report by the Intergovernmental Panel on Climate Change—which we are hearing more about today—continues to confirm our fears about global warming.

I hope that as the American people and the international community continue to learn about this report and the effects of global warming, our renewed interest in the topic will turn into action.

The United States is the world leader in the emission of greenhouse gases. That means we have a moral obligation to lead the world to a solution.

I believe that America's ingenuity, and our unique spirit can be an incredible asset in this cause. Our action on global warming can also help restore our authority as a respected global leader.

Developing sound policy on global warming—and investing in new technologies and clean energy—can help grow our economy too.

This Congress, the President and the American people have a responsibility, and I hope that we re-dedicate ourselves to meeting that responsibility.

[The prepared statement by Mr. Ehlers follows:]

PREPARED STATEMENT OF REPRESENTATIVE VERNON J. EHLERS

I am pleased that the Science and Technology Committee is hearing from scientists who participated in the Intergovernmental Panel on Climate Change, especially so soon after the Summary for Policy-makers was released. We're fortunate to receive this information "hot off the presses" (if I am allowed to think that anything "hot" is a good thing given today's topic).

In my mind, there are three big questions related to climate change. One, is climate change happening? Two, to what extent is it anthropogenic? And three, what are we going to do about it? I believe that the research the panelists will discuss today advances our knowledge of the answers on the first and second of these questions. We need to hear how the methods of monitoring changes in the Earth have improved, and what the most recent data indicates, especially since the last major assessment was finalized in 2001. But an even bigger task for this committee and our colleagues is to answer the third question: what are we going to do about climate change? Comprehensive and continuing science is critical for us to be able to answer that question. The additional working groups of the IPCC also will help address the broader policy questions of climate change strategy, and I look forward to reviewing those results in the spring.

Our planet is a dynamic system, and any attempts to mitigate warming, adapt to sea level rise, or any other response to climate change will rely on scientific research and researchers, like those testifying before us today. These individuals have dedicated not just hours, but years to the process that results in the full assessment of climate science due in May. I thank them for that commitment, and look forward to the opportunity to hearing what they have to say.

[The prepared statement by Mr. Neugebauer follows:]

PREPARED STATEMENT OF REPRESENTATIVE RANDY NEUGEBAUER

Mr. Chairman:

Thank you for holding this hearing. I welcome the opportunity to take part in this important discussion and look forward to hearing from our distinguished panelists.

Like everyone else, and despite the recent record cold temperatures here in DC and around the country, I believe the Earth has gotten warmer over the past century. I don't doubt that there is consensus on that fact. Beyond that, however, I see a lot of disagreement.

On the one hand, we have the distinguished scientists before us who have authored key findings of the IPCC's report. They—and others—believe "with more than 90 percent confidence" that, based on their models and data, human activity is chiefly responsible for global warming since the 1950s.

On the other hand, we have other distinguished scientists who disagree with that assessment. Some believe that humans, to varying degrees, have played a role in global warming. Others believe that solar activity has been the primary factor, given their models and data.

The bottom line, Mr. Chairman, is that the scientific community does not speak with one voice on this important issue. And that's not unusual. It happens all the time with scientific inquiry. New models are developed; data is re-examined; new hypotheses are tested. That's normal and healthy—when you have a robust scientific community free of political or ideological interference.

But Mr. Chairman, what I've seen lately has been disturbing—and it should concern every American. Scientists who disagree with the popular view on global warming are being ostracized. They are being labeled "global warming deniers." We have politicians and activists—most of whom are not scientists themselves—working to silence highly trained and accredited scientists. Some call for silencing their disagreement by revoking professional certifications and removing them from key positions.

Mr. Chairman, why has the reaction to these differing scientific findings been so extreme and so reckless? I strongly suspect that ideology, not scientific disagreement, is behind this reaction.

Mr. Chairman, *it is an inconvenient truth that we run a terrible danger when scientific debate is stifled because it gets in the way of political goals.*

We in Congress, and in this committee especially, are called upon to make scientific and environmental policy that will affect our economy, our security, and our general welfare; and not just for us, but for future generations of Americans, as well.

To the best of my knowledge, none of us sitting on this committee are climatologists or meteorologists or otherwise competent on our own merits to claim full knowledge of this complex issue. So, we deserve to have all the scientific information before us—to consider it, and to make the wisest policy choices based on all the findings before us.

Mr. Chairman, you have indicated that it's time to end the debate on this issue. But I respectfully disagree with that assessment. It is plain that the debate has just begun.

I hope future hearings on global warming will provide the opportunity to hear opposing views and have a full healthy debate and dialogue on this issue.

Thank you.

Chairman GORDON. I ask unanimous consent that Representative Gilchrest, who was a former Member of this committee, be permitted, at his request, to sit at the dais for this hearing and that he be permitted to ask questions after all Members of the Committee have an opportunity to question the witnesses. Mr. Sensenbrenner, is that okay with you?

Mr. SENSENBRENNER. I just want to see the rules followed.

Chairman GORDON. All right. Thank you. Without objection, so ordered.

Now it is my pleasure and privilege to welcome the Speaker of the House of Representatives, Nancy Pelosi, to be with us today. I know this is an issue that you are both informed about and have a passion about. And we welcome you here for this hearing and welcome to hear your remarks.

Panel I:

STATEMENT OF THE HONORABLE NANCY PELOSI, SPEAKER OF THE HOUSE OF REPRESENTATIVES

Speaker PELOSI. Thank you very much, Mr. Chairman.

I thank you and your distinguished Ranking Member, Mr. Hall, for the courtesy extended here today for me to present my views before this very important committee.

The last time I was in this room was for the unveiling of the portrait of Mr. Boehlert, and here we are, portrait and Mr. Boehlert, as well, and I join you in thanking him for his great leadership to our country and in working in a bipartisan way to use science as a basis for progress in our country.

I want to also join in commending the witnesses who will be presenting today. I thank them for their extraordinary contribution to understanding of climate change. Their new report confirms that climate change is indisputably underway and states with 90 percent certainty that greenhouse gases released by human activities are the main cause of global warming.

I am very pleased to see on the wall, which in the excitement of Mr. Boehlert's unveiling, I didn't see that day several months ago, that you quote Tennyson, who is my favorite poet, Alfred Lord Tennyson. And it says, "For I dipped into the future, as far as human eyes could see, saw the vision of the world and all the wonder that would be." What a wonderful inspiration to the work of this committee.

You, on this committee, are opening a window into our future. Looking through that window, we see a future in which global warming will reshape our planet and our society. We also see a future in which harsh consequences could be blunted by prompt action. That is the good news.

This is an issue that is as immediate to the American people as their own neighborhoods and as global as the planet itself. It was interesting to me that on a recent visit from the Executive Committee of the U.S. Conference of Mayors, a bipartisan Committee, they brought forth their 10-point program for strong cities, strong families, a strong America. And point number one in the Conference of Mayors' 10-point proposal was energy independence, climate change, global warming. That was their top priority. They had best practices, that they, in a bipartisan way, are sharing with each other and instituting in their communities. Again, this is as immediate to the lives of the American people as their own neighborhoods, and again, it is as global as the planet. And that—more on that in just a moment.

On the science of global warming, the level of carbon dioxide in the atmosphere is by far the highest in 650,000 years. Temperatures are estimated to rise anywhere from two degrees Fahrenheit to as high as 11.5 degrees by the end of the century. We can expect rising sea levels, more intense storms, increased drought in some areas and more floods in others, heat waves, spread of tropical diseases, extinction of species, changes in ocean salinity, and melting ice in the polar regions, and that is already happening.

The catastrophic hurricanes of 2005, Katrina and Rita, foreshadow the challenges we will face. All along our coastlines, our great cities and small towns will be threatened by rising sea levels and intensifying storms.

Not only coastal areas will be affected. Inland communities will be gravely affected as well by drought and flood. Movement of climate change refugees from one country to another could increase political instability in many regions of the world. These environmental refugees are a real, real concern.

Looking through the window into the future that you have opened, we also see that we can reshape our activities now and prevent catastrophic global warming. Where once we thought the effects of global warming would occur decades away, change is already underway.

We hold our children's future in our hands, not our grandchildren, or great-grandchildren, but our own children. As the most adaptable creatures on the planet, it is time for us to continue to adapt.

Scientific evidence suggests that to prevent the most severe effects of global warming, we will need to cut global greenhouse gas emissions roughly in half from today's levels by 2050. The Bush Administration continues to oppose mandatory limits on greenhouse gases, restating this position immediately upon the release of the IPCC report. I respectfully disagree with the distinguished Ranking Member in his comments, and this is a wonderful venue for the debate, this very important committee with these very informed Members.

I do believe, though, Mr. Hall and Mr. Chairman, we cannot achieve the transformation we need, both in the United States and throughout the international community, without mandatory action to reduce greenhouse gas pollution. Many of the technologies to revolutionize our use of energy are already at hand, as the distinguished gentleman mentioned, and we can develop others, waiting on the shelf, or under development. Restrictions on greenhouse gas emissions will drive these technologies into the marketplace quickly and cost-effectively, while simultaneously creating the next generation of good-paying new jobs.

In addition, we must address land-use policies in the U.S. and worldwide, since the loss of forests currently contributes about 25 percent of global carbon dioxide emissions. Older forests can store more carbon while also providing fuel for biomass energy in a sustainable manner.

We have a responsibility to work together with countries, as the distinguished Ranking Member Mr. Hall said, but these other countries, India and China, to name two, to work with them for them to reduce the level of carbon dioxide in the atmosphere. That may be as important to our grandchildren and our children's future as anything we do here. The United States and China, as well as India, are the largest contributors of carbon dioxide emissions in the world, and it is estimated that China will surpass the United States in three years.

We need to engage the Chinese government by working cooperatively to develop clean and renewable sources of energy.

I have asked the Chairs of the committees of jurisdiction to work with their Ranking Members in a bipartisan way with the Members of the Committees to develop legislation over energy, environment, and technology policy and to report that legislation to us no later than June 1 so that we can have an energy independence global warming package by the 4th of July.

This committee is way ahead of the rest. It has legislation, as has been mentioned, on the Floor today, and I commend you for that, Chairman Gordon and Mr. Hall and Members of the Committee. I know that you have other legislation that relates to innovation and the innovation agenda, which is directly related to this issue that will help advance the technologies needed to help save our planet.

We hope to have legislation that will be a starting point on global warming and energy independence soon. Again, you have taken the lead.

I also want to mention that we are creating a Select Committee on Energy Independence and Global Warming to raise the visibility of these urgent issues and gather critical information to protect America's security. This is a national security issue. The Select Committee will not have legislative jurisdiction, but will develop policy strategies, technologies and other innovations intended to reduce the dependence of the United States on foreign sources of energy, and to achieve substantial and permanent reductions in emissions and other activities that contribute to climate change and global warming. The Select Committee will share its findings with the legislative committees of the House and with the public, and they will make a special effort to communicate with younger Americans by using the most cutting-edge technologies. Young people are very concerned about the issue of global warming. It is natural, because the future is theirs, and this has a big impact on the future.

For 12 years, the leadership in the House of Representatives has stifled all discussion and debate on global warming. The long rejection of reality is over, to the relief of Members, I believe, on both sides of the aisle.

We teach our children, Mr. Chairman and Ranking and other Members of the Committee, that everything in nature is connected, and indeed, it is. The Bible tells us in the Old Testament that, "To minister to the needs of God's creation is an act of worship. To ignore those needs is to dishonor the God who made us." Indeed, this planet is God's creation. That is why large segments of the evangelical movement have become part of this effort to curb and stop global warming. We have a responsibility to make an act of worship by protecting God's creation.

There is a growing chorus of voices, including evangelicals, in favor of taking serious and sustained action on global warming, from scientists to Fortune 100 CEOs, from evangelical Christians to environmentalists, from farmers to hunters and anglers. We will work together, holding hearings, developing legislation, and tackling one of America's—humanity's—greatest challenges yet: global warming.

With that, Mr. Chairman, I thank you, once again, for the opportunity to present my views as Speaker of the House to you and to Mr. Hall with the promise that this is not about taking one point of view and going forward but in trying to work in a bipartisan way for sustainable initiatives that we can agree upon and make a difference for our children and see "the vision of the world and all the wonder that would be" in this important committee. Thank you, Mr. Chairman.

[The prepared statement of Ms. Pelosi follows:]

PREPARED STATEMENT OF SPEAKER NANCY PELOSI

Thank you, Chairman Gordon, for holding this important hearing on the findings of the Fourth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC). Thank you, Ranking Member Hall, and my colleagues on the Science and Technology Committee for your attention to the pressing issue of climate change.

To the witnesses appearing today, thank you for your extraordinary contributions to our understanding of climate science. Your new report confirms that climate change is indisputably underway and states with 90 percent certainty that greenhouse gases released by human activities are the main cause of global warming.

You have opened a window into our future. Looking through that window, we see a future in which global warming will reshape our planet and society. We also see a future in which harsh consequences could be blunted by our prompt action.

The level of carbon dioxide in the atmosphere is by far the highest in 650,000 years. Temperatures are estimated to rise anywhere from two degrees Fahrenheit to as high as 11.5 degrees by the end of the century. We can expect rising sea levels, more intense storms, increased drought in some areas and more floods in others, heat waves, spread of tropical diseases, extinction of regions.

The catastrophic hurricanes of 2005, Katrina and Rita, foreshadow the challenges we will face. All along our coastlines, our great cities and small towns will be threatened by rising sea levels and intensifying storms.

Not only coastal areas will be affected. Inland communities will be gravely affected as well by drought and flood. Movement of climate change refugees from one country to another could increase political instability in many regions of the world.

Looking through the window into the future that you have opened, we also see that we can reshape our activities now and prevent catastrophic global warming. Where once we thought the effects of global warming would occur decades underway.

We hold our children's future in our hands—not our grandchildren, or great-grandchildren, but our own children. As the most adaptable creatures on time for us to adapt.

Scientific evidence suggests that to prevent the most severe effects of global warming, we will need to cut global greenhouse gas emissions roughly in half from today's levels species, changes in ocean salinity, and melting ice in the polar away, change is already the planet, it is by 2050. The Bush Administration continues to oppose mandatory limits on greenhouse gases, restating this position immediately upon the release of the IPCC report.

We cannot achieve the transformation we need, both in the United States and throughout the international community, without mandatory action to reduce greenhouse gas pollution. Many of the technologies to revolutionize our use of energy are already at hand, waiting on the shelf, or under development. Restrictions on greenhouse gas emissions will drive these technologies into the marketplace quickly and cost-effectively, while simultaneously creating the next generation of good-paying new jobs.

In addition, we must address land-use policies in the U.S. and worldwide, since the loss of forests currently contributes about 25 percent of global carbon dioxide emissions. Older forests can store more carbon while also providing fuel for biomass energy in a sustainable manner.

We have a responsibility to work together with countries such as China to reduce the level of carbon dioxide in the atmosphere. The United States and China are the two largest contributors of carbon dioxide emissions in the world and it is estimated that China will surpass the U.S. in just three years.

We need to engage the Chinese Government by working cooperatively to develop clean and renewable sources of energy.

I have also asked the committees that have jurisdiction over energy, environment and technology policy to report legislation on these issues by June. We hope to have legislation that will be a starting point on global warming and energy independence through the committees by July 4th, so that this year, Independence Day is also Energy Independence Day.

We are creating a Select Committee on Energy Independence and Global Warming to raise the visibility of these urgent issues and gather critical information to protect America's security. The Select Committee will not have legislative jurisdiction, but they will develop recommendations on policies, strategies, technologies and other innovations intended to reduce the dependence of the United States on foreign sources of energy, and to achieve substantial and permanent reductions in emissions and other activities that contribute to climate change and global warming. The Select Committee will share its findings with the legislative committees of the House and with the public, and they will make a special effort to communicate with younger Americans by using the most cutting-edge technology.

For twelve years, the leadership in the House of Representatives stifled all discussion and debate of global warming. That long rejection of reality is over, to the relief of Members on both sides of the aisle.

The Bible tells us in the Old Testament, 'To minister to the needs of God's creation is an act of worship. To ignore those needs is to dishonor the God who made us.'

There is a growing chorus of voices in favor of taking serious and sustained action on global warming: from scientists to Fortune 100 CEOs, from evangelical Christians to environmentalists, from farmers to hunters and anglers. We will work together, holding hearings, developing legislation, and tackling one of humanity's greatest challenges yet global warming.

Discussion

Chairman Gordon. Speaker, thank you for joining us today. You are the first Speaker to be before this committee. I have only been here 22 years, but you are the first Speaker that I know of in those 22 years to make a presentation before any committee, and I suspect this may be groundbreaking in the history of the Congress, which I think demonstrates your passion and leadership on this issue, and we appreciate you being here.

My Ranking Member Hall and I have no questions. We are going to let Mr. Sensenbrenner have his question, and then I am going to ask that we have unanimous consent that any further questions be submitted by writing.

Mr. Sensenbrenner.

Well, then Mr. Sensenbrenner will have the first question.

ECONOMIC IMPACTS OF CLIMATE CHANGE

Mr. SENSENBRENNER. Thank you very much, Madame Speaker.

Speaker PELOSI. Thank you, Mr. Sensenbrenner.

Mr. SENSENBRENNER. I welcome you here today.

Speaker PELOSI. Thank you.

Mr. SENSENBRENNER. I hope that you and your successors engage in the debate on the issues before the Congress, and I think that this is a very welcome development.

I really do have to take issue with your comment in your statement that for 12 years there was no discussion of global warming, because during my chairmanship of this committee, and particularly in 1998 and 1999, we had a number of hearings at the Full and Subcommittee level relative to the Kyoto protocol, the science behind it, and the economic consequences this ratification would entail to the United States and its workers. One of those witnesses was the head of the Energy Information Agency in the Department of Energy who was a direct appointee of President Clinton. And this man testified that the ratification of Kyoto and the caps that are similar to that which you are advocating, would cause a 60 to 80 percent increase in the cost of natural gas, electricity, and fuel oil to the American consumer. And given the fact that China is not under any caps and as late as last week said that they didn't want to do that, I would ask you to look at the impact on American jobs, because we do not want to have anything we do result in the outsourcing of American jobs to countries like China and India and Mexico that have not capped or even slowed down their growth in greenhouse gas emissions. What are you planning to do, Madame Speaker, to make sure that we don't legislate on this area in a way that wrecks the American economy and costs our workers jobs?

Speaker PELOSI. Thank you, Mr. Sensenbrenner.

Whatever actions we take have to be based, I believe, on science and on the facts. And one fact is that America must innovate in this arena for us to be ahead. We look forward to doing this in a bipartisan way. We know that there will be impacts on the coal industry, on other sources of energy, and we want to hear what those industries have to say. So this isn't about running roughshod. This is about working together. And hopefully we can work in a bipartisan way with the President of the United States in order to do this. I see it as an economic opportunity, a place where green can be gold for our country where the technologies we develop for dealing with the coal industry and other industries in our country on which we are dependent now for energy using their initiatives, because they are making change, and we have to listen to them as well, to Mr. Rahall and Mr. Boucher, who represent these districts, Members of the Republican party who represent them as well.

So what we want to do is do something where we have as much unity as possible, and we certainly are sensitive to the issue of economic growth in our country.

Mr. SENSENBRENNER. Well, Madame Speaker, just to follow up, I would make the observation that there are two sides to the equation. One is the scientific side and relative to emissions of greenhouse gases. The other is the economic consequences of any actions that we take. And you know, I am very fearful the way this debate has been joined and, given who the witnesses are following you, that we are looking at one side of the equation and ignoring the other side, and we can't do that for the sake of American jobs.

And I yield back the balance of my time.

Speaker PELOSI. Yes, I agree with that, Mr. Sensenbrenner. We can't ignore it, but we also can't ignore the consequences of not doing something, because that will have an economic impact as well.

SELECT COMMITTEE ON ENERGY INDEPENDENCE AND GLOBAL WARMING

Chairman GORDON. Thank you. Mr. Sensenbrenner, I will point out that the Minority had the right to submit witnesses. I think that you had one. You withdrew him. And so this was not a rigged jury, but rather it may be by default. Maybe no one else wanted to come up and speak. But that is where we are.

Madame Speaker, as we gather together here, I know you had mentioned earlier, again, your passion for this and that you wanted to develop a Select Committee. Could you tell us more about that Select Committee and why it is so important and what you want to do with it?

Speaker PELOSI. Thank you, Mr. Chairman.

There are eight or nine committees of jurisdiction on this issue ranging from this important committee, the Ways and Means Committee, the International Relations Committee, as has been pointed out by Mr. Sensenbrenner, and the distinguished Ranking Member, other countries have a big impact on how we go forward on this issue. And so this Select Committee was designed to try to get some of the best information possible by communicating directly in the cities of America where, again, best practices are being used to address this issue, where the bipartisan Conference of Mayors is putting forth global warming and energy independence as their top priority in their 10-point program, working with the governors, working with leaders around the world. The European Union is way ahead of us on this issue. They see it as an economic issue, Mr. Sensenbrenner. They see it as an economic issue. They know that they want to be out there in front with the technologies that will enable us to curb global warming, and that is in our economic interest. The United Nations, of course we have this report, but the United Nations has this as a priority as well.

I have asked this—a Select Committee to—whether it is as local as a neighborhood, as global as the planet, to help communicate this message, get the best possible information. I could have done it as a task force within the Democratic party, but I wanted it to be bipartisan so we had every point of view represented, different views in our own party as well as views within the Republican party so that as we go forward, we are doing so in a way that is understanding the consequences of it.

So it is a way for us to communicate with the next generation of leaders in our country, to communicate with countries that have a big impact on global warming like China and India, communicate to the neighborhoods of America that everyone is involved in this decision, because everyone is affected by it. And we want to go forward in a temperate way but in a bold way to make a difference for our children.

So that is the purpose of it. It does not have legislative authority. It will end at the end of this Congress, and I think it will be a force for good.

Chairman GORDON. Mr. Hall.

Mr. HALL. Mr. Chairman, I have no questions for this speaker. And we did invite, from the United States Chamber of Commerce one of the great bodies of advice for this committee. They said they did not have the time to answer the political questions. They thought it was going to be on science alone. It is not that. And we will have them before you later.

I yield back any time that you might yield to me.

Chairman GORDON. Well, Mr. Hall, I think you will find that the IPCC Report is the scientific definitive statement on this issue and we look forward to hearing that.

Let us see. Is there anyone else on the top row?

Mr. Akin.

NUCLEAR ENERGY

Mr. AKIN. Thank you, Mr. Chairman.

And I appreciate your allowing us to ask a few questions. And it is a very interesting debate. Madame Speaker, thank you for joining us this morning.

Speaker PELOSI. Thank you.

Mr. AKIN. Your comments, you laid out a couple of basic premises that you were assuming. The first premise is that the Earth is getting warmer. I don't think there is a lot of debate on that. I think the Earth is getting warmer.

The second one is maybe another question that is interesting. It is being caused by our burning hydrocarbons. If, in fact, you apparently believe that to be true, my question is, do you endorse the expansion of nuclear energy, because that does not burn hydrocarbons?

Speaker PELOSI. Mr. Akin, in the early days of my life in the Congress, I was an opponent of nuclear energy, because I didn't know what was going to be done—how we would dispose of the waste from it.

Your question is a good one, because the technology has changed, and I bring a more open mind to that subject now, because I think we have to look at the technology and really compare it to what the alternatives. If they are looking at India and we are looking at China and looking at them putting on more coal-burning plants than we have in the United States, that they are just going to even add now, and the alterative might be nuclear, we have to weigh what that does to the environment. But I think that the answer is always with technology. If we can't—if the technology is at a place where we can dispose of the waste, well, let us at least try to move it to that place. But I have a different view of nuclear energy than I did, say, 20 years ago when I came to this——

Mr. AKIN. I think what I hear you saying is that you would—assuming that a reasonable proposal could be made, that nuclear could be the substitute for burning hydrocarbons.

Speaker PELOSI. Well, I would say I would not, as I did in my youth, be an active opponent of such a thing, but hope that we would work together to take it to a place where we can dispose of the waste. That is the big challenge. But I will say this. Again, we have to always compare it to if not this, then what, and what does that do in terms of global warming. So I think it has to be on the table.

Mr. AKIN. That is interesting. I appreciate your open-mindedness to that alternative.

Speaker PELOSI. I do have an open mind.

THE INTERNATIONAL BANKING ENVIRONMENTAL PROTECTION ACT

Mr. AKIN. That is something from an engineering perspective—I am one of the few engineers, I guess, that managed to get into Congress. Perhaps by mistake, but that is something that has always seemed very logical, even though there was sort of a political prejudice against it. The global or geophysical research letters estimated in 1997 that if the Earth, that is all of the nations, lived up to the United Nation's Kyoto protocol on global warming, that we would prevent no more than 0.1 to 6 degrees Fahrenheit of warming in 50 years. That says that you are talking about some pretty strong actions that are going to have to be taken. I think this makes fixing Social Security look easy by comparison. And I guess I am wondering, you talk about the fact that we have got the highest level of CO_2 in 650,000 years. I guess my question is, how was it that Greenland was harvesting corn in the year, what, 900 or 1000 if the CO_2 was so high? Or was there something else making the world warm? And is it so bad if it gets warmer?

Speaker PELOSI. Well, that is a very good question. About 19 or 18 years ago, early in my term in Congress, I had a piece of legislation that was called the International Banking Environmental Protection Act, and it goes right to your final question. That was a bill that said—that talked about the International Bank, the World Bank, the Interamerican Bank, the Asian—all of the multi-development banks. It was a piece of legislation that I introduced on the Banking Committee. And at the time, I had opposition from my fellow Democrats on the legislation because it called for an environmental impact statement to be made on any projects that the United States would vote on and that the results of that impact statement would be made known to the indigenous people of the region as well as internationally. So that is the bottom line of it.

At the very same time—now this had to be—President Bush was President, so it was after President Reagan, so it was, say, 1990, something like that. At that time, the President of the World Bank said, a very distinguished gentleman, but this is what he said. He said, "What difference does it make if there is global warming, if there is climate change? We can just go develop those countries where the snow—those areas where the snow is melting." It wasn't really a very informed statement, and that was, again, like 1990, and it did more to pass my bill than anything I could do, even getting past the Democrats on the Committee who were not particularly well inclined, and President Bush signed it into law.

Mr. AKIN. I guess——

Speaker PELOSI. But there was a reality at the time, and there are serious consequences to global warming, and we have to face that reality.

Chairman GORDON. The gentleman's time is up. I would——

Mr. AKIN. Thank you, Mr. Chairman.

Chairman GORDON.—suggest that it may not matter to Missouri about global warming, but if Greenland loses all of its ice and snow, then our friends around the coast are going to be concerned about it, because there will be an enormous amount of flooding. I recognize——

Mr. HALL. Mr. Chairman, would you yield?

Chairman GORDON. Yes, Mr. Hall.

Mr. HALL. I think what you are really saying is if we really want to alter the warming trend significantly, we are going to have to cut emissions by a very large amount, even beyond Kyoto. And the question is, that I think the gentleman is asking down there, is do we currently have affordable technologies for significantly reducing greenhouse gas emissions, and is there any estimate of cost, and who pays? I think that is the major question. That is the reason the gentleman from——

Speaker PELOSI. That is a good answer.

Chairman GORDON. That is a good——

Mr. HALL. The U.S. Chamber did not want to come on such short notice.

Chairman GORDON. Well, I have a high regard for the Chamber and their intelligence and their ability, and I think that they could have made a good statement, but you have raised a good question. The good news is we have a panel of scientists that just got through working on a report with 113 nations, I think 6,000 scientists, approved by this country and this President, and we are going to hear from them with those very specific answers, and I am glad we are going to be able to do that.

Mr. Costello.

QUESTION AND ANSWER SESSION: CONGRESSIONAL CUSTOMS

Mr. COSTELLO. Mr. Chairman, thank you.

Mr. Chairman, I do not have any questions for the distinguished Speaker, but let me say that I am very disappointed and very surprised that we have not extended to this witness, to the Speaker of the House, the same courtesy that we have extended to many Members of the House of Representatives since I have served on this committee.

I have served on the Science Committee for 18 years. As I recall under the leadership, I think the record will reflect, under the distinguished Chairman Sherry Boehlert, under Mr. Sensenbrenner, under every Chairman of this committee since I have been there serving on this committee, I can recall many Members of Congress testifying, presenting their statement before this committee, and we extended the courtesy to them because of demanding schedules, let alone the Speaker of the House of Representatives, allowed them to submit their testimony and to leave without going through the long ordeal of questions.

I serve on the Transportation and Infrastructure Committee, as Mr. Boehlert did in his service in the Congress. We extended the same courtesy there to countless Members of Congress, and I just have to tell you that I am extremely surprised. This is the first, but it won't be the last time that we are going to debate this issue in this committee and a whole host of other committees. So I just have to tell you, I am very disappointed and very surprised.

Mr. ROHRABACHER. Would the gentleman yield?

Mr. COSTELLO. We are—I will in just one second. That we are subjecting the Speaker of the House of Representatives to a higher standard than we have extended the courtesy to other Members. Again, I——

Mr. ROHRABACHER. Would the gentleman yield?

Mr. COSTELLO. Yes, I will.

Mr. ROHRABACHER. I agree with you.

Speaker PELOSI. Thank you, Dana.

Chairman GORDON. Well, the good news is that we have a great Speaker who can handle herself very well.

Speaker PELOSI. I do have to leave.

Chairman GORDON.We have to reset our timer, and so as we do that, I am going to recess this committee.

Speaker PELOSI. And may I just—may I thank you, Mr. Chairman?

Chairman GORDON. Yes, you may.

Speaker PELOSI. May I thank the distinguished Chairman and Ranking Member, Members of the Committee. It is the first committee that I have testified before as Speaker of the House. And because you are a committee about the future, I think that is perfectly appropriate. I wish you much success in your deliberations.

Thank you, Mr. Chairman.

Chairman GORDON. You made this a better hearing. Thank you.

Speaker PELOSI. Thank you.

Chairman GORDON. And we are in recess.

[Recess.]

Chairman GORDON. Thank you all. We have our clocks working again. And now that we have our equipment back in shape, we will recommence. And I will call this committee back to order, and I would like to call our panel of witnesses to the table. Thank you.

We are very pleased to have this distinguished panel of climate scientists here for this morning. All of our four witnesses have just returned from Paris where they have participated in the preparation of the Summary for Policy-makers release by the IPCC last Friday.

I will begin by introducing Mr. Richard Alley. Mr. Alley is a Professor of geosciences and an associate of Earth and Environmental Systems Institute at the Pennsylvania State University. Mr. Alley is an expert in the area of glaciers and ice sheets and their potential to cause changes in the sea level. He serves on the National Academy of Sciences' Polar Research Board and chaired the NAS Panel on Abrupt Climate Change. Mr. Alley was a Lead Author of

Chapter 4 of the IPCC Report dealing with changes in snow, ice, and frozen ground.

I will now yield to Representative Udall, if Mr. Udall is here, yes, to introduce the remaining three panelists who are members and constituents from his district.

Mr. Udall.

Mr. UDALL. Thank you, Mr. Chairman. And many of you on the Committee know that Boulder is home to many outstanding climate science facilities, including NOAA's Earth System Research Laboratory and the National Center for Atmospheric Research.

And I want to start with Dr. Susan Solomon. She serves as the Co-Chair of Working Group I of the IPCC, and she provided overall coordination for the report. Dr. Solomon received her Ph.D. in chemistry from the University of California at Berkeley in 1981 and currently is a senior scientist at NOAA's Earth System Research Laboratory. A couple of interesting background facts about Dr. Solomon, she has a glacier named after her in the Antarctic because of her work on the causes of the ozone hole. She is a member of the National Academy of Sciences. And in March of 2000, she received the National Medal of Science, the United States' highest scientific honor, for her "Key on Insights in Explaining the Cause of the Antarctic Ozone Hole." She has also written a book, which is of great interest to me as an aging mountaineer, called "The Coldest March," which covers the tragic story of Captain Robert Falcon Scott and his British team, who in November 1911, began a trek across the snows of the Antarctic, striving to be the first to reach the South Pole. And Dr. Solomon, I can't help but wonder if the lessons learned from Scott's and Amundsen's expeditions to the South Pole could be applied to this similarly long, challenging, and crucial journey to stabilize and reduce greenhouse gases.

Next to Dr. Solomon is Dr. Kevin Trenberth. Dr. Trenberth served as a Coordinating Lead Author for Chapter 3 of the report, "Observations, Surface, and Atmospheric Climate Change." Currently, he is the head of the climate analysis section at the National Center for Atmospheric Research (NCAR), originally from New Zealand, who obtained his doctorate in meteorology in 1972 from MIT. He was named a fellow of the American Meteorological Society in 1985 and the American Association for the Advancement of Science in 1994. He has published over 400 scientific articles or papers, including 40 books or book chapters and over 175 referee journal articles, and he is listed among the top 20 authors in Hyatt citations and all of geophysics. He has also recently served as a member of the National Oceanic and Atmospheric Administration Climate Working Group from 1987 to 2006 and is a member of NOAA's Climate Observing System Council and NOAA's Advisory Panel for Climate Change Data and Detection.

At the end of the table is Dr. Gerald Meehl. Dr. Meehl is the Coordinating Lead Author for Chapter 10 of the report, "Global Climate Projections." Dr. Meehl received his Ph.D. in climate dynamics from the University of Colorado in 1987. His expertise is in the field of climate modeling. He has been a scientist on staff at NCAR since 1979. Dr. Meehl has long been involved with the IPCC, having been a member of the Working Group I Report group since 1989 and has participated in the development of several IPCC assessment reports. He is the author of more than 140 scientific papers and peer-review journals. He has also, since 1979, as a scientist in the Climate and Global Dynamics Division, studied the interactions between El Niño, the Southern Oscillation, and the Indian monsoon, analyzed the results from global-coupled ocean atmosphere general circulation models at NCAR, and examined the possible effects of increased carbon dioxide, sulfate, aerosols, and other forcings on global climate.

We are really proud to have you three here today. Thank you for taking your valuable time to share your conclusions and your observations.

Thank you, Mr. Chairman.

Chairman GORDON. Thank you, Mr. Udall.

This is a very, very distinguished panel, and we know this has been a hectic period for you, and we do appreciate you being here. Each of you will be allowed five minutes, but in the spirit of our former Chairman, I don't know whether he was embarrassed and left, but Sherry Boehlert was here earlier, he would say to witnesses of your nature that 300 seconds is not very much to talk about these very serious problems, so we hope you will be quick, because we want to have questions, but we want you to take the time that you need to make the points that need to be.

So Dr. Solomon, please begin.

Panel II:

STATEMENT OF DR. SUSAN SOLOMON, CO-CHAIR, IPCC, WORKING GROUP I: THE PHYSICAL BASIS OF CLIMATE CHANGE; SENIOR SCIENTIST, EARTH SYSTEM RESEARCH LABORATORY, OFFICE OF OCEANIC AND ATMOSPHERIC RESEARCH, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, U.S. DEPARTMENT OF COMMERCE

Dr. SOLOMON. Thank you. I would like to thank Chairperson Gordon, Ranking Member Hall, and the other Members of the Committee for the opportunity to talk with you today on the Working Group I Report of the IPCC. I appreciate very much the generous introduction by Mr. Udall. I would just like to add that I have served as an author on various reports of the IPCC beginning in 1992.

In 2002, I was greatly honored to be formally nominated by the United States of America to Co-Chair the Fourth Assessment of Working Group I, the part that deals with physical climate science.

The IPCC was established under the World Meteorological Organization and the United Nations Environment Program to provide regular assessments for policy-makers on the scientific, technical, and socio-economic aspects of climate change. Today, we will be talking about the scientific aspects of climate change, the physical science basis. IPCC does not do, nor does it manage, research. It provides assessment reports covering the state of scientific understanding based upon the scientific literature. Each report is written by international experts on a volunteer basis. IPCC's past reports have been highly praised by many organizations, such as scientific academies around the world, including our own U.S. National Academy of Sciences.

The 152 primary authors of the Working Group I's Fourth Assessment Report come from every inhabited continent in the world. About 75 percent of those authors did not work on the Third Assessment Report, the last previous report, guaranteeing a fresh look. About a quarter of the authors are young, in the professional sense, having had their highest degree for less than 10 years at the time that we started our work. Over 600 experts participated in two rounds of open review. And in addition to the experts, dozens of governments also provided formal coordinated reviews, including our own government. In total, the Working Group I scientific assessment received over 30,000 comments. To put those numbers in perspective, a typical research paper published in a scientific journal is subject to review by two or three experts. It may receive a few dozen comments. A distinguished team of 27 review editors, who are independent of the author teams, played an oversight role, ensuring that all substantive review comments were given appropriate consideration. It took over two years to write, review, revise and finalize the document, giving us a product that we believe is unique in many ways; not least the fact that it is not the view of any one scientist or a few scientists but rather reflects an extremely broad-ranging synthesis of scientific viewpoints. It indicates what is known, and also what is not known, and remaining uncertainties.

A different Working Group covers impacts and adaptation and another covers mitigation and policy options. The reports of these other two groups will be delivered later this spring.

And now I would like to briefly turn to some key highlights of our own Report, the key messages of this document.

Greenhouse gases have increased markedly since 1750 and are now at levels unprecedented in many thousands of years. The warming is unequivocal. Our planet is warming. That is evident in many different types of observations. Most of the warming of the past 50 years is very likely due to greenhouse gas increases. We believe that has a 9-out-of-10 chance based on a very careful detailed assessment that accounts for solar and volcanic effects, that takes into account many factors, including the simple fact that the recent years have been remarkably warm, and the chances of that happening at random are quite small.

We are already committed to further warming. Even if we were to stabilize all greenhouse gases now, instead of having continuing increases. And in that regard, the rate of increase of carbon dioxide of the past 10 years was the largest since direct measurements began in 1960.

Continued emissions at or above current rates will very likely lead to larger changes in the 21st century than those of the 20th. The effects expected include: more heavy rain, more drought, more heat waves, and more sea level rise. How much depends on how much we choose to emit on a global basis.

Sea level rise is expected to increase due to expansion of water in a warmer world. Changes in ice sheets are currently contributing about 12 percent to the total sea level rise of the past decade. That could grow or it could decrease in the future. And I will leave it to Dr. Alley to talk more about that.

And thank you very, very much for the invitation and for your attention.

[The prepared statement of Dr. Solomon follows:]

PREPARED STATEMENT OF SUSAN SOLOMON

I thank Chairperson Gordon, Ranking Member Hall, and the other Members of the Committee for the opportunity to speak with you today on the Working Group I report of the Intergovernmental Panel on Climate Change 2007 Report (IPCC, 2007). My name is Susan Solomon and I am a Senior Scientist at NOAA's Earth System Research Laboratory in Boulder, Colorado. I've been a scientist at NOAA for more than 26 years. Much of my work over that time has focused on understanding the cause of ozone depletion. In 2000, I received this nation's highest scientific award, the National Medal of Science, in recognition of that work. I've also been honored with membership in the U.S. National Academy of Sciences and I am a foreign associate of the French Academy of Sciences and the Acadamiae Europaea. In addition to my research on ozone depletion, I also do personal research on climate change, in particular on the range of chemicals that contribute to climate change. I'm the author or co-author of more than 150 scientific publications, and I've served as an author on various reports of the Intergovernmental Panel on Climate Change beginning in 1992.

In 2002, I had the honor of being formally nominated by the United States of America to co-chair Working Group I, the part of the IPCC that deals with physical climate science. I was selected by the IPCC Panel of governments to serve in that role, and for almost the past five years have accordingly co-chaired the process that resulted in the 2007 Working Group I Assessment Report, together with Dr. Qin Dahe of China. We are assisted by six able vice-chairs from around the world and by a technical support unit that provides logistical and related functions.

The Intergovernmental Panel on Climate Change was established under the auspices of the World Meteorological Organization and the United Nations Environment Program to provide regular assessments for policy-makers of the scientific, technical and socio-economic aspects climate change. IPCC does not do or manage research. It provides assessment reports covering the state of scientific understanding based upon the scientific literature. Each report is written by international experts on a volunteer basis. IPCC has produced its major assessments every five to six years since 1990, and the 2007 report is the fourth in that series. The Working Group Co-Chairs and Vice-Chairs select authors on the basis of their scientific publications and products from among nominees proposed by governments, with due regard for geographic balance. IPCC's reports have been highly praised by many organizations such as scientific academies around the world including our own U.S. National Academy of Sciences.

The 152 authors of the Working Group I Fourth Assessment Report hail from every inhabited continent in the world. About 75 percent of these authors did not work on the previous 2001 report. About a quarter of the authors are young in the professional sense, having had their highest degree for less than 10 years at the time we began our work. Over 400 other scientists have served as contributing authors. Over 600 experts participated in two rounds of open review. In addition to the experts, dozens of governments also provided formal coordinated reviews. In total, the Working Group I assessment received over 30,000 comments. To put these numbers in perspective, a typical research paper published in a scientific journal is subject to review by two or three experts. It may receive a few dozen comments. A distinguished team of 27 review editors, who are independent of the author teams, played an oversight role ensuring that all substantive review comments were given appropriate consideration. It took over two years to write, review, revise and finalize the document. The product is unique in many ways, not least the fact that it is not the view of any one scientist or a few scientists but rather reflects an extremely broad-ranging synthesis of scientific viewpoints.

A different Working Group (Working Group II), covers impacts and adaptation and another (Working Group III) covers mitigation and policy options. The reports of these other two groups are due to be released later this spring. There will also be a Synthesis Report released in November, 2007, which endeavors to provide a synthesis of all three Working Group reports.

The Summary for Policy-makers of the Working Group I was approved by the governments of the IPCC Panel in Paris last week. That document is appended here as the scientific basis of my testimony.

WMO INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE UNEP

Climate Change 2007: The Physical Science Basis

Summary for Policymakers

Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change

This Summary for Policymakers was formally approved at the 10th Session of Working Group I of the IPCC, Paris, February 2007.

Note:
Text, tables and figures given here are final but subject to checking and copy-editing and editorial adjustments to figures.

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INTRODUCTION

The Working Group I contribution to the IPCC Fourth Assessment Report describes progress in understanding of the human and natural drivers of climate change[1], observed climate change, climate processes and attribution, and estimates of projected future climate change. It builds upon past IPCC assessments and incorporates new findings from the past six years of research. Scientific progress since the TAR is based upon large amounts of new and more comprehensive data, more sophisticated analyses of data, improvements in understanding of processes and their simulation in models, and more extensive exploration of uncertainty ranges.

The basis for substantive paragraphs in this Summary for Policymakers can be found in the chapter sections specified in curly brackets.

HUMAN AND NATURAL DRIVERS OF CLIMATE CHANGE

Changes in the atmospheric abundance of greenhouse gases and aerosols, in solar radiation and in land surface properties alter the energy balance of the climate system. These changes are expressed in terms of radiative forcing[2], which is used to compare how a range of human and natural factors drive warming or cooling influences on global climate. Since the Third Assessment Report (TAR), new observations and related modelling of greenhouse gases, solar activity, land surface properties and some aspects of aerosols have led to improvements in the quantitative estimates of radiative forcing.

Global atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years (see Figure SPM-1). The global increases in carbon dioxide concentration are due primarily to fossil fuel use and land-use change, while those of methane and nitrous oxide are primarily due to agriculture. {2.3, 6.4, 7.3}

- Carbon dioxide is the most important anthropogenic greenhouse gas (see Figure SPM-2). The global atmospheric concentration of carbon dioxide has increased from a pre-industrial value of about 280 ppm to 379 ppm[3] in 2005. The atmospheric concentration of carbon dioxide in 2005 exceeds by far the natural range over the last 650,000 years (180 to 300 ppm) as determined from ice cores. The annual carbon dioxide concentration growth-rate was larger during the last 10 years (1995 – 2005 average: 1.9 ppm per year), than it has been since the beginning of continuous direct atmospheric measurements (1960–2005 average: 1.4 ppm per year) although there is year-to-year variability in growth rates.
- The primary source of the increased atmospheric concentration of carbon dioxide since the pre-industrial period results from fossil fuel use, with land use change providing another significant but smaller contribution. Annual fossil carbon dioxide emissions[4] increased from an average of 6.4 [6.0 to 6.8][5] GtC

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[1] *Climate change* in IPCC usage refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the Framework Convention on Climate Change, where climate change refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods.

[2] *Radiative forcing* is a measure of the influence that a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system and is an index of the importance of the factor as a potential climate change mechanism. Positive forcing tends to warm the surface while negative forcing tends to cool it. In this report radiative forcing values are for 2005 relative to pre-industrial conditions defined at 1750 and are expressed in watts per square metre ($W m^{-2}$). See Glossary and Section 2.2 for further details.

[3] ppm (parts per million) or ppb (parts per billion, 1 billion = 1,000 million) is the ratio of the number of greenhouse gas molecules to the total number of molecules of dry air. For example: 300 ppm means 300 molecules of a greenhouse gas per million molecules of dry air.

[4] Fossil carbon dioxide emissions include those from the production, distribution and consumption of fossil fuels and as by product from cement production. An emission of 1 GtC corresponds to 3.67 $GtCO_2$.

[5] In general, uncertainty ranges for results given in this Summary for Policymakers are 90% uncertainty intervals unless stated otherwise, i.e., there is an estimated 5% likelihood that the value could be above the range given in square brackets and 5% likelihood that the value could be below that range. Best estimates are given where available. Assessed uncertainty intervals are not always symmetric about the corresponding best estimate. Note that a number of uncertainty ranges in the Working Group I TAR corresponded to 2-sigma (95%), often using expert judgement.

(23.5 [22.0 to 25.0] $GtCO_2$) per year in the 1990s, to 7.2 [6.9 to 7.5] GtC (26.4 [25.3 to 27.5] $GtCO_2$) per year in 2000–2005 (2004 and 2005 data are interim estimates). Carbon dioxide emissions associated with land-use change are estimated to be 1.6 [0.5 to 2.7] GtC (5.9 [1.8 to 9.9] $GtCO_2$) per year over the 1990s, although these estimates have a large uncertainty. {2.3, 7.3}

- The global atmospheric concentration of methane has increased from a pre-industrial value of about 715 ppb to 1732 ppb in the early 1990s, and is 1774 ppb in 2005. The atmospheric concentration of methane in 2005 exceeds by far the natural range of the last 650,000 years (320 to 790 ppb) as determined from ice cores. Growth rates have declined since the early 1990s, consistent with total emissions (sum of anthropogenic and natural sources) being nearly constant during this period. It is *very likely*[6] that the observed increase in methane concentration is due to anthropogenic activities, predominantly agriculture and fossil fuel use, but relative contributions from different source types are not well determined. {2.3, 7.4}
- The global atmospheric nitrous oxide concentration increased from a pre-industrial value of about 270 ppb to 319 ppb in 2005. The growth rate has been approximately constant since 1980. More than a third of all nitrous oxide emissions are anthropogenic and are primarily due to agriculture. {2.3,7.4}

The understanding of anthropogenic warming and cooling influences on climate has improved since the Third Assessment Report (TAR), leading to *very high confidence*[7] that the globally averaged net effect of human activities since 1750 has been one of warming, with a radiative forcing of +1.6 [+0.6 to +2.4] W m^{-2}. (see Figure SPM-2). {2.3. 6.5, 2.9}

- The combined radiative forcing due to increases in carbon dioxide, methane, and nitrous oxide is +2.30 [+2.07 to +2.53] W m^{-2}, and its rate of increase during the industrial era is *very likely* to have been unprecedented in more than 10,000 years (see Figures SPM-1 and SPM-2). The carbon dioxide radiative forcing increased by 20% from 1995 to 2005, the largest change for any decade in at least the last 200 years. {2.3, 6.4}
- Anthropogenic contributions to aerosols (primarily sulphate, organic carbon, black carbon, nitrate and dust) together produce a cooling effect, with a total direct radiative forcing of -0.5 [-0.9 to -0.1] W m^{-2} and an indirect cloud albedo forcing of -0.7 [-1.8 to -0.3] W m^{-2}. These forcings are now better understood than at the time of the TAR due to improved *in situ*, satellite and ground-based measurements and more comprehensive modelling, but remain the dominant uncertainty in radiative forcing. Aerosols also influence cloud lifetime and precipitation. {2.4, 2.9, 7.5}
- Significant anthropogenic contributions to radiative forcing come from several other sources. Tropospheric ozone changes due to emissions of ozone-forming chemicals (nitrogen oxides, carbon monoxide, and hydrocarbons) contribute +0.35 [+0.25 to +0.65] W m^{-2}. The direct radiative forcing due to changes in halocarbons[8] is +0.34 [+0.31 to +0.37] W m^{-2}. Changes in surface albedo, due to land-cover changes and deposition of black carbon aerosols on snow, exert respective forcings of -0.2 [-0.4 to 0.0] and +0.1 [0.0 to +0.2] W m^{-2}. Additional terms smaller than $\pm$0.1 W m^{-2} are shown in Figure SPM-2. {2.3, 2.5, 7.2}
- Changes in solar irradiance since 1750 are estimated to cause a radiative forcing of +0.12 [+0.06 to +0.30] W m^{-2}, which is less than half the estimate given in the TAR. {2.7}

[6] In this Summary for Policymakers, the following terms have been used to indicate the assessed likelihood, using expert judgement, of an outcome or a result: *Virtually certain* > 99% probability of occurrence, *Extremely likely* > 95%, *Very likely* > 90%, *Likely* > 66%, *More likely than not* > 50%, *Unlikely* < 33%, *Very unlikely* < 10%, *Extremely unlikely* < 5%. (See Box TS 1.1 for more details).

[7] In this Summary for Policymakers the following levels of confidence have been used to express expert judgments on the correctness of the underlying science: *very high confidence* at least a 9 out of 10 chance of being correct; *high confidence* about an 8 out of 10 chance of being correct. (See Box TS-1.1)

[8] Halocarbon radiative forcing has been recently assessed in detail in IPCC's Special Report on Safeguarding the Ozone Layer and the Global Climate System (2005).

DIRECT OBSERVATIONS OF RECENT CLIMATE CHANGE

Since the TAR, progress in understanding how climate is changing in space and in time has been gained through improvements and extensions of numerous datasets and data analyses, broader geographical coverage, better understanding of uncertainties, and a wider variety of measurements. Increasingly comprehensive observations are available for glaciers and snow cover since the 1960s, and for sea level and ice sheets since about the past decade. However, data coverage remains limited in some regions.

Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global mean sea level (see Figure SPM-3). {3.2, 4.2, 5.5}

- Eleven of the last twelve years (1995 -2006) rank among the 12 warmest years in the instrumental record of global surface temperature[8] (since 1850). The updated 100-year linear trend (1906–2005) of 0.74 [0.56 to 0.92]°C is therefore larger than the corresponding trend for 1901-2000 given in the TAR of 0.6 [0.4 to 0.8]°C. The linear warming trend over the last 50 years (0.13 [0.10 to 0.16]°C per decade) is nearly twice that for the last 100 years. The total temperature increase from 1850 – 1899 to 2001 – 2005 is 0.76 [0.57 to 0.95]°C. Urban heat island effects are real but local, and have a negligible influence (less than 0.006°C per decade over land and zero over the oceans) on these values. {3.2}
- New analyses of balloon-borne and satellite measurements of lower- and mid-tropospheric temperature show warming rates that are similar to those of the surface temperature record and are consistent within their respective uncertainties, largely reconciling a discrepancy noted in the TAR. {3.2, 3.4}
- The average atmospheric water vapour content has increased since at least the 1980s over land and ocean as well as in the upper troposphere. The increase is broadly consistent with the extra water vapour that warmer air can hold. {3.4}
- Observations since 1961 show that the average temperature of the global ocean has increased to depths of at least 3000 m and that the ocean has been absorbing more than 80% of the heat added to the climate system. Such warming causes seawater to expand, contributing to sea level rise (Table SPM-0). {5.2, 5.5}

[8] The average of near surface air temperature over land, and sea surface temperature.

Table SPM-0. Observed rate of sea level rise and estimated contributions from different sources. {5.5, Table 5.3} [Numbers to be converted to mm per year]

Source of sea level rise	Rate of sea level rise (m per century) 1961 – 2003	1993 – 2003
Thermal expansion	0.042 ± 0.012	0.16 ± 0.05
Glaciers and ice caps	0.050 ± 0.018	0.077 ± 0.022
Greenland ice sheets	0.05 ± 0.12	0.21 ± 0.07
Antarctic ice sheets	0.14 ± 0.41	0.21 ± 0.35
Sum of individual climate contributions to sea level rise	0.11 ± 0.05	0.28 ± 0.07
Observed total sea level rise	0.18 ± 0.05[a]	0.31 ± 0.07[a]
Difference (Observed minus sum of estimated climate contributions)	0.07 ± 0.07	0.03 ± 0.10

Note:
[a] Data prior to 1993 are from tide gauges and after 1993 are from satellite altimetry

- Mountain glaciers and snow cover have declined on average in both hemispheres. Widespread decreases in glaciers and ice caps have contributed to sea level rise (ice caps do not include contributions from the Greenland and Antarctic ice sheets). (see Table SPM-0) {4.6, 4.7, 4.8, 5.5}
- New data since the TAR now show that losses from the ice sheets of Greenland and Antarctica have very likely contributed to sea level rise over 1993 to 2003 (Table SPM-0). Flow speed has increased for some Greenland and Antarctic outlet glaciers, which drain ice from the interior of the ice sheets. The corresponding increased ice sheet mass loss has often followed thinning, reduction or loss of ice shelves or loss of floating glacier tongues. Such dynamical ice loss is sufficient to explain most of the Antarctic net mass loss and approximately half of the Greenland net mass loss. The remainder of the ice loss from Greenland has occurred because losses due to melting have exceeded accumulation due to snowfall. {4.6, 4.8, 5.5}
- Global average sea level rose at an average rate of 1.8 [1.3 to 2.3] mm per year over 1961 to 2003. The rate was faster over 1993 to 2003, about 3.1 [2.4 to 3.8] mm per year. Whether the faster rate for 1993 to 2003 reflects decadal variability or an increase in the longer-term trend is unclear. There is *high confidence* that the rate of observed sea level rise increased from the 19th to the 20th century. The total 20th century rise is estimated to be 0.17 [0.12 to 0.22] m. {5.5}
- For 1993-2003, the sum of the climate contributions is consistent within uncertainties with the total sea level rise that is directly observed (see Table SPM-0). These estimates are based on improved satellite and *in-situ* data now available. For the period of 1961 to 2003, the sum of climate contributions is estimated to be smaller than the observed sea level rise. The TAR reported a similar discrepancy for 1910 to 1990. {5.5}

At continental, regional, and ocean basin scales, numerous long-term changes in climate have been observed. These include changes in Arctic temperatures and ice, widespread changes in precipitation amounts, ocean salinity, wind patterns and aspects of extreme weather including droughts, heavy precipitation, heat waves and the intensity of tropical cyclones[10]. {3.2, 3.3, 3.4, 3.5, 3.6, 5.2}

[10] Tropical cyclones include hurricanes and typhoons.

- Average Arctic temperatures increased at almost twice the global average rate in the past 100 years. Arctic temperatures have high decadal variability, and a warm period was also observed from 1925 to 1945. {3.2}
- Satellite data since 1978 show that annual average Arctic sea ice extent has shrunk by 2.7 [2.1 to 3.3]% per decade, with larger decreases in summer of 7.4 [5.0 to 9.8]% per decade. These values are consistent with those reported in the TAR. {4.4}
- Temperatures at the top of the permafrost layer have generally increased since the 1980s in the Arctic (by up to 3°C). The maximum area covered by seasonally frozen ground has decreased by about 7% in the Northern Hemisphere since 1900, with a decrease in spring of up to 15%. {4.7}
- Long-term trends from 1900 to 2005 have been observed in precipitation amount over many large regions.[11] Significantly increased precipitation has been observed in eastern parts of North and South America, northern Europe and northern and central Asia. Drying has been observed in the Sahel, the Mediterranean, southern Africa and parts of southern Asia. Precipitation is highly variable spatially and temporally, and data are limited in some regions. Long-term trends have not been observed for the other large regions assessed.[11] {3.3, 3.9}
- Changes in precipitation and evaporation over the oceans are suggested by freshening of mid and high latitude waters together with increased salinity in low latitude waters. {5.2}
- Mid-latitude westerly winds have strengthened in both hemispheres since the 1960s. {3.5}
- More intense and longer droughts have been observed over wider areas since the 1970s, particularly in the tropics and subtropics. Increased drying linked with higher temperatures and decreased precipitation have contributed to changes in drought. Changes in sea surface temperatures (SST), wind patterns, and decreased snowpack and snow cover have also been linked to droughts. {3.3}
- The frequency of heavy precipitation events has increased over most land areas, consistent with warming and observed increases of atmospheric water vapour. {3.8, 3.9}
- Widespread changes in extreme temperatures have been observed over the last 50 years. Cold days, cold nights and frost have become less frequent, while hot days, hot nights, and heat waves have become more frequent (see Table SPM-1). {3.8}
- There is observational evidence for an increase of intense tropical cyclone activity in the North Atlantic since about 1970, correlated with increases of tropical sea surface temperatures. There are also suggestions of increased intense tropical cyclone activity in some other regions where concerns over data quality are greater. Multi-decadal variability and the quality of the tropical cyclone records prior to routine satellite observations in about 1970 complicate the detection of long-term trends in tropical cyclone activity. There is no clear trend in the annual numbers of tropical cyclones. {3.8}

Some aspects of climate have not been observed to change. {3.2, 3.8, 4.4, 5.3}

- A decrease in diurnal temperature range (DTR) was reported in the TAR, but the data available then extended only from 1950 to 1993. Updated observations reveal that DTR has not changed from 1979 to 2004 as both day- and night-time temperature have risen at about the same rate. The trends are highly variable from one region to another. {3.2}
- Antarctic sea ice extent continues to show inter-annual variability and localized changes but no statistically significant average trends, consistent with the lack of warming reflected in atmospheric temperatures averaged across the region. {3.2, 4.4}
- There is insufficient evidence to determine whether trends exist in the meridional overturning circulation of the global ocean or in small scale phenomena such as tornadoes, hail, lightning and dust-storms. {3.8, 5.3}

[11] The assessed regions are those considered in the regional projections Chapter of the TAR and in Chapter 11 of this Report.

Table SPM-1. Recent trends, assessment of human influence on the trend, and projections for extreme weather events for which there is an observed late 20th century trend. {Tables 3.7, 3.8, 9.4, Sections 3.8, 5.5, 9.7, 11.2-11.9}

Phenomenon[a] and direction of trend	**Likelihood that trend occurred in late 20th century (typically post 1960)**	**Likelihood of a human contribution to observed trend[b]**	**Likelihood of future trends based on projections for 21st century using SRES scenarios**
Warmer and fewer cold days and nights over most land areas	*Very likely*[c]	*Likely*[e]	*Virtually certain*[e]
Warmer and more frequent hot days and nights over most land areas	*Very likely*[d]	*Likely (nights)*[e]	*Virtually certain*[e]
Warm spells / heat waves. Frequency increases over most land areas	*Likely*	*More likely than not*[f]	*Very likely*
Heavy precipitation events. Frequency (or proportion of total rainfall from heavy falls) increases over most areas	*Likely*	*More likely than not*[f]	*Very likely*
Area affected by droughts increases	*Likely* in many regions since 1970s	*More likely than not*	*Likely*
Intense tropical cyclone activity increases	*Likely* in some regions since 1970	*More likely than not*[f]	*Likely*
Increased incidence of extreme high sea level (excludes tsunamis)[g]	*Likely*	*More likely than not*[f, h]	*Likely*[i]

Notes:
(a) See Table 3.7 for further details regarding definitions
(b) See Table TS-4, Box TS-3.4 and Table 9.4.
(c) Decreased frequency of cold days and nights (coldest 10%)
(d) Increased frequency of hot days and nights (hottest 10%)
(e) Warming of the most extreme days and nights each year
(f) Magnitude of anthropogenic contributions not assessed. Attribution for these phenomena based on expert judgement rather than formal attribution studies.
(g) Extreme high sea level depends on mean sea level and on regional weather systems. It is defined here as the highest 1% of hourly values of observed sea level at a station for a given reference period.
(h) Changes in observed extreme high sea level closely follow the changes in mean sea level {5.5.2.6}. It is *very likely* that anthropogenic activity contributed to a rise in mean sea level. {9.5.2}
(i) In all scenarios, the projected global mean sea level at 2100 is higher than in the reference period. {10.6}. The effect of changes in regional weather systems on sea level extremes has not been assessed.

A Paleoclimatic Perspective

Paleoclimatic studies use changes in climatically sensitive indicators to infer past changes in global climate on time scales ranging from decades to millions of years. Such proxy data (e.g., tree ring width) may be influenced by both local temperature and other factors such as precipitation, and are often representative of particular seasons rather than full years. Studies since the TAR draw increased confidence from additional data showing coherent behaviour across multiple indicators in different parts of the world. However, uncertainties generally increase with time into the past due to increasingly limited spatial coverage.

Paleoclimate information supports the interpretation that the warmth of the last half century is unusual in at least the previous 1300 years. The last time the polar regions were significantly warmer than present for an extended period (about 125,000 years ago), reductions in polar ice volume led to 4 to 6 metres of sea level rise. {6.4, 6.6}

- Average Northern Hemisphere temperatures during the second half of the 20th century were *very likely* higher than during any other 50-year period in the last 500 years and *likely* the highest in at least the past 1300 years. Some recent studies indicate greater variability in Northern Hemisphere temperatures than suggested in the TAR, particularly finding that cooler periods existed in the 12 to 14th, 17th, and 19th centuries. Warmer periods prior to the 20th century are within the uncertainty range given in the TAR. {6.6}
- Global average sea level in the last interglacial period (about 125,000 years ago) was *likely* 4 to 6 m higher than during the 20th century, mainly due to the retreat of polar ice. Ice core data indicate that average polar temperatures at that time were 3 to 5°C higher than present, because of differences in the Earth's orbit. The Greenland ice sheet and other Arctic ice fields *likely* contributed no more than 4 m of the observed sea level rise. There may also have been a contribution from Antarctica. {6.4}

Understanding and Attributing Climate Change

This Assessment considers longer and improved records, an expanded range of observations, and improvements in the simulation of many aspects of climate and its variability based on studies since the TAR. It also considers the results of new attribution studies that have evaluated whether observed changes are quantitatively consistent with the expected response to external forcings and inconsistent with alternative physically plausible explanations.

Most of the observed increase in globally averaged temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations[12]. This is an advance since the TAR's conclusion that "most of the observed warming over the last 50 years is *likely* to have been due to the increase in greenhouse gas concentrations". Discernible human influences now extend to other aspects of climate, including ocean warming, continental-average temperatures, temperature extremes and wind patterns (see Figure SPM-4 and Table SPM-1). {9.4, 9.5}

- It is *likely* that increases in greenhouse gas concentrations alone would have caused more warming than observed because volcanic and anthropogenic aerosols have offset some warming that would otherwise have taken place. {2.9, 7.5, 9.4}
- The observed widespread warming of the atmosphere and ocean, together with ice mass loss, support the conclusion that it is *extremely unlikely* that global climate change of the past fifty years can be explained without external forcing, and very likely that it is not due to known natural causes alone. {4.8, 5.2, 9.4, 9.5, 9.7}

[12] Consideration of remaining uncertainty is based on current methodologies.

- Warming of the climate system has been detected in changes of surface and atmospheric temperatures, temperatures in the upper several hundred metres of the ocean and in contributions to sea level rise. Attribution studies have established anthropogenic contributions to all of these changes. The observed pattern of tropospheric warming and stratospheric cooling is *very likely* due to the combined influences of greenhouse gas increases and stratospheric ozone depletion. {3.2, 3.4, 9.4, 9.5}
- It is *likely* that there has been significant anthropogenic warming over the past 50 years averaged over each continent except Antarctica (see Figure SPM-4). The observed patterns of warming, including greater warming over land than over the ocean, and their changes over time, are only simulated by models that include anthropogenic forcing. The ability of coupled climate models to simulate the observed temperature evolution on each of six continents provides stronger evidence of human influence on climate than was available in the TAR. {3.2, 9.4}
- Difficulties remain in reliably simulating and attributing observed temperature changes at smaller scales. On these scales, natural climate variability is relatively larger making it harder to distinguish changes expected due to external forcings. Uncertainties in local forcings and feedbacks also make it difficult to estimate the contribution of greenhouse gas increases to observed small-scale temperature changes. {8.3, 9.4}
- Anthropogenic forcing is *likely* to have contributed to changes in wind patterns[13], affecting extra-tropical storm tracks and temperature patterns in both hemispheres. However, the observed changes in the Northern Hemisphere circulation are larger than simulated in response to 20th century forcing change. {3.5, 3.6, 9.5, 10.3}
- Temperatures of the most extreme hot nights, cold nights and cold days are *likely* to have increased due to anthropogenic forcing. It is *more likely than not* that anthropogenic forcing has increased the risk of heat waves (see Table SPM-1). {9.4}

Analysis of climate models together with constraints from observations enables an assessed likely range to be given for climate sensitivity for the first time and provides increased confidence in the understanding of the climate system response to radiative forcing. {6.6, 8.6, 9.6. Box 10.2}

- The equilibrium climate sensitivity is a measure of the climate system response to sustained radiative forcing. It is not a projection but is defined as the global average surface warming following a doubling of carbon dioxide concentrations. It is *likely* to be in the range 2 to 4.5°C with a best estimate of about 3°C, and is *very unlikely* to be less than 1.5°C. Values substantially higher than 4.5°C cannot be excluded, but agreement of models with observations is not as good for those values. Water vapour changes represent the largest feedback affecting climate sensitivity and are now better understood than in the TAR. Cloud feedbacks remain the largest source of uncertainty. {8.6, 9.6, Box 10.2}
- It is *very unlikely* that climate changes of at least the seven centuries prior to 1950 were due to variability generated within the climate system alone. A significant fraction of the reconstructed Northern Hemisphere interdecadal temperature variability over those centuries is very likely attributable to volcanic eruptions and changes in solar irradiance, and it is likely that anthropogenic forcing contributed to the early 20th century warming evident in these records. {2.7, 2.8, 6.6, 9.3}

[13] In particular, the Southern and Northern Annular Modes and related changes in the North Atlantic Oscillation {3.6, 9.5, Box TS.3.1}

Projections of Future Changes in Climate

A major advance of this assessment of climate change projections compared with the TAR is the large number of simulations available from a broader range of models. Taken together with additional information from observations, these provide a quantitative basis for estimating likelihoods for many aspects of future climate change. Model simulations cover a range of possible futures including idealised emission or concentration assumptions. These include SRES[14,15] illustrative marker scenarios for the 2000–2100 period and model experiments with greenhouse gases and aerosol concentrations held constant after year 2000 or 2100.

For the next two decades a warming of about 0.2°C per decade is projected for a range of SRES emission scenarios. Even if the concentrations of all greenhouse gases and aerosols had been kept constant at year 2000 levels, a further warming of about 0.1°C per decade would be expected. {10.3, 10.7}

- Since IPCC's first report in 1990, assessed projections have suggested global averaged temperature increases between about 0.15 and 0.3°C per decade for 1990 to 2005. This can now be compared with observed values of about 0.2°C per decade, strengthening confidence in near-term projections. {1.2, 3.2}
- Model experiments show that even if all radiative forcing agents are held constant at year 2000 levels, a further warming trend would occur in the next two decades at a rate of about 0.1°C per decade, due mainly to the slow response of the oceans. About twice as much warming (0.2°C per decade) would be expected if emissions are within the range of the SRES scenarios. Best-estimate projections from models indicate that decadal-average warming over each inhabited continent by 2030 is insensitive to the choice among SRES scenarios and is *very likely* to be at least twice as large as the corresponding model-estimated natural variability during the 20th century. {9.4, 10.3, 10.5, 11.2–11.7, Figure TS-29}

Continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would *very likely* be larger than those observed during the 20th century. {10.3}

- Advances in climate change modelling now enable best estimates and *likely* assessed uncertainty ranges to be given for projected warming for different emission scenarios. Results for different emission scenarios are provided explicitly in this report to avoid loss of this policy-relevant information. Projected globally-averaged surface warmings for the end of the 21st century (2090–2099) relative to 1980–1999 are shown in Table SPM-2. These illustrate the differences between lower to higher SRES emission scenarios and the projected warming uncertainty associated with these scenarios. {10.5}
- Best estimates and likely ranges for globally average surface air warming for six SRES emissions marker scenarios are given in this assessment and are shown in Table SPM-2. For example, the best estimate for the low scenario (B1) is 1.8°C (likely range is 1.1°C to 2.9°C), and the best estimate for the high scenario (A1FI) is 4.0°C (likely range is 2.4°C to 6.4°C). Although these projections are broadly consistent with the span quoted in the TAR (1.4 to 5.8°C), they are not directly comparable (See Figure A). The AR4 is more advanced as it provides best estimates and an assessed likelihood range for each of the marker scenarios. The new assessment of the likely ranges now relies on a larger number of climate models of increasing complexity and realism, as well as new information regarding the nature of feedbacks from the carbon cycle and constraints on climate response from observations.

[14] SRES refers to the IPCC Special Report on Emission Scenarios (2000). The SRES scenario families and illustrative cases, which did not include additional climate initiatives, are summarized in a box at the end of this Summary for Policymakers. Approximate CO_2 equivalent concentrations corresponding to the computed radiative forcing due to anthropogenic greenhouse gases and aerosols in 2100 (see p. 823 of the TAR) for the SRES B1, A1T, B2, A1B, A2 and A1FI illustrative marker scenarios are about 600, 700, 800, 850, 1250 and 1550 ppm respectively.

[15] Scenarios B1, A1B, and A2 have been the focus of model inter-comparison studies and many of these results are assessed in this report.

- Warming tends to reduce land and ocean uptake of atmospheric carbon dioxide, increasing the fraction of anthropogenic emissions that remains in the atmosphere. For the A2 scenario, for example, the climate-carbon cycle feedback increases the corresponding global average warming at 2100 by more than 1°C. Assessed upper ranges for temperature projections are larger than in the TAR (see Table SPM-2) mainly because the broader range of models now available suggests stronger climate-carbon cyclefeed backs.. {7.3, 10.5}

Table SPM-2. Projected globally averaged surface warming and sea level rise at the end of the 21st century for different model cases. The sea level projections do not include uncertainties in carbon-cycle feedbacks, because a basis in published literature is lacking. {10.5, 10.6, Table 10.7}

	Temperature Change (°C at 2090-2099 relative to 1980-1999) [a]		Sea Level Rise (m at 2090-2099 relative to 1980-1999)
Case	Best estimate	*Likely* range	Model-based range excluding future rapid dynamical changes in ice flow
Constant Year 2000 concentrations [c]	0.6	0.3 – 0.9	NA
B1 scenario	1.8	1.1 – 2.9	0.18 – 0.38
A1T scenario	2.4	1.4 – 3.8	0.20 – 0.45
B2 scenario	2.4	1.4 – 3.8	0.20 – 0.43
A1B scenario	2.8	1.7 – 4.4	0.21 – 0.48
A2 scenario	3.4	2.0 – 5.4	0.23 – 0.51
A1FI scenario	4.0	2.4 – 6.4	0.26 – 0.59

Notes:

[a] These estimates are assessed from a hierarchy of models that encompass a simple climate model, several EMICs, and a large number of AOGCMs.

[c] Year 2000 constant composition is derived from AOGCMs only

- Model-based projections of global average sea level rise at the end of the 21st century (2090-2099) are shown in Table SPM-2. For each scenario, the midpoint of the range in Table SPM-2 is within 10% of the TAR model average for 2090-2099. The ranges are narrower than in the TAR mainly because of improved information about some uncertainties in the projected contributions.[16] {10.6}
- Models used to date do not include uncertainties in climate-carbon cycle feedback nor do they include the full effects of changes in ice sheet flow, because a basis in published literature is lacking. The projections include a contribution due to increased ice flow from Greenland and Antarctica at the rates observed for 1993-2003, but these flow rates could increase or decrease in the future. For example, if this contribution were to grow linearly with global average temperature change, the upper ranges of sea level rise for SRES scenarios shown in Table SPM-2 would increase by 0.1 m to 0.2 m. Larger values cannot be excluded, but understanding of these effects is too limited to assess their likelihood or provide a best estimate or an upper bound for sea level rise. {10.6}

[16] TAR projections were made for 2100, whereas projections in this Report are for 2090-2099. The TAR would have had similar ranges to those in Table SPM-2 if it had treated the uncertainties in the same way.

- Increasing atmospheric carbon dioxide concentrations lead to increasing acidification of the ocean. Projections based on SRES scenarios give reductions in average global surface ocean pH[17] of between 0.14 and 0.35 units over the 21st century, adding to the present decrease of 0.1 units since pre-industrial times. {5.4, Box 7.3, 10.4}

There is now higher confidence in projected patterns of warming and other regional-scale features, including changes in wind patterns, precipitation, and some aspects of extremes and of ice. {8.2, 8.3, 8.4, 8.5, 9.4, 9.5, 10.3, 11.1}

- Projected warming in the 21st century shows scenario-independent geographical patterns similar to those observed over the past several decades. Warming is expected to be greatest over land and at most high northern latitudes, and least over the Southern Ocean and parts of the North Atlantic ocean (see Figure SPM-5). {10.3}
- Snow cover is projected to contract. Widespread increases in thaw depth are projected over most permafrost regions. {10.3, 10.6}
- Sea ice is projected to shrink in both the Arctic and Antarctic under all SRES scenarios. In some projections, Arctic late-summer sea ice disappears almost entirely by the latter part of the 21st century. {10.3}
- It is *very likely* that hot extremes, heat waves, and heavy precipitation events will continue to become more frequent. {10.3}
- Based on a range of models, it is likely that future tropical cyclones (typhoons and hurricanes) will become more intense, with larger peak wind speeds and more heavy precipitation associated with ongoing increases of tropical SSTs. There is less confidence in projections of a global decrease in numbers of tropical cyclones. The apparent increase in the proportion of very intense storms since 1970 in some regions is much larger than simulated by current models for that period. {9.5, 10.3, 3.8}
- Extra-tropical storm tracks are projected to move poleward, with consequent changes in wind, precipitation, and temperature patterns, continuing the broad pattern of observed trends over the last half-century. {3.6, 10.3}
- Since the TAR there is an improving understanding of projected patterns of precipitation. Increases in the amount of precipitation are *very likely* in high-latitudes, while decreases are likely in most subtropical land regions (by as much as about 20% in the A1B scenario in 2100, see Figure SPM-6), continuing observed patterns in recent trends. {3.3, 8.3, 9.5, 10.3, 11.2 to 11.9}
- Based on current model simulations, it is *very likely* that the meridional overturning circulation (MOC) of the Atlantic Ocean will slow down during the 21st century. The multi-model average reduction by 2100 is 25% (range from zero to about 50%) for SRES emission scenario A1B. Temperatures in the Atlantic region are projected to increase despite such changes due to the much larger warming associated with projected increases of greenhouse gases. It is very unlikely that the MOC will undergo a large abrupt transition during the 21st century. Longer-term changes in the MOC cannot be assessed with confidence. {10.3, 10.7}

Anthropogenic warming and sea level rise would continue for centuries due to the timescales associated with climate processes and feedbacks, even if greenhouse gas concentrations were to be stabilized. {10.4, 10.5, 10.7}

- Climate-carbon cycle coupling is expected to add carbon dioxide to the atmosphere as the climate system warms, but the magnitude of this feedback is uncertain. This increases the uncertainty in the trajectory of carbon dioxide emissions required to achieve a particular stabilisation level of atmospheric carbon dioxide concentration. Based on current understanding of climate carbon cycle feedback, model studies suggest that

[17] Decreases in pH correspond to increases in acidity of a solution. See Glossary for further details.

to stabilise at 450 ppm carbon dioxide, could require that cumulative emissions over the 21st century be reduced from an average of approximately 670 [630 to 710] GtC to approximately 490 [375 to 600] GtC. Similarly, to stabilise at 1000 ppm this feedback could require that cumulative emissions be reduced from a model average of approximately 1415 [1340 to 1490] GtC to approximately 1100 [980 to 1250] GtC. {7.3, 10.4} [Add $GtCO_2$ numbers].

- If radiative forcing were to be stabilized in 2100 at B1 or A1B levels[10] a further increase in global mean temperature of about 0.5°C would still be expected, mostly by 2200. {10.7}
- If radiative forcing were to be stabilized in 2100 at A1B levels[11], thermal expansion alone would lead to 0.3 to 0.8 m of sea level rise by 2300 (relative to 1980–1999). Thermal expansion would continue for many centuries, due to the time required to transport heat into the deep ocean. {10.7}
- Contraction of the Greenland ice sheet is projected to continue to contribute to sea level rise after 2100. Current models suggest ice mass losses increase with temperature more rapidly than gains due to precipitation and that the surface mass balance becomes negative at a global average warming (relative to pre-industrial values) in excess of 1.9 to 4.6°C. If a negative surface mass balance were sustained for millennia, that would lead to virtually complete elimination of the Greenland ice sheet and a resulting contribution to sea level rise of about 7 m. The corresponding future temperatures in Greenland are comparable to those inferred for the last interglacial period 125,000 years ago, when paleoclimatic information suggests reductions of polar land ice extent and 4 to 6 m of sea level rise. {6.4, 10.7}
- Dynamical processes related to ice flow not included in current models but suggested by recent observations could increase the vulnerability of the ice sheets to warming, increasing future sea level rise. Understanding of these processes is limited and there is no consensus on their magnitude. {4.6, 10.7}
- Current global model studies project that the Antarctic ice sheet will remain too cold for widespread surface melting and is expected to gain in mass due to increased snowfall. However, net loss of ice mass could occur if dynamical ice discharge dominates the ice sheet mass balance. {10.7}
- Both past and future anthropogenic carbon dioxide emissions will continue to contribute to warming and sea level rise for more than a millennium, due to the timescales required for removal of this gas from the atmosphere. {7.3, 10.3}

The Emission Scenarios of the IPCC Special Report on Emission Scenarios (SRES)[18]

A1. The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end use technologies).

A2. The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.

B1. The B1 storyline and scenario family describes a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives.

B2. The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

An illustrative scenario was chosen for each of the six scenario groups A1B, A1FI, A1T, A2, B1 and B2. All should be considered equally sound.

The SRES scenarios do not include additional climate initiatives, which means that no scenarios are included that explicitly assume implementation of the United Nations Framework Convention on Climate Change or the emissions targets of the Kyoto Protocol.

[18] Emission scenarios are not assessed in this Working Group One report of the IPCC. This box summarizing the SRES scenarios is taken from the TAR and has been subject to prior line by line approval by the Panel.

Changes in Greenhouse Gases
from Ice-Core and Modern Data

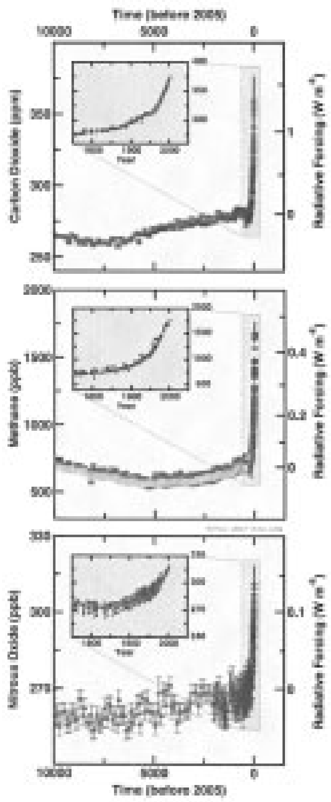


FIGURE SPM-1. Atmospheric concentrations of carbon dioxide, methane and nitrous oxide over the last 10,000 years (large panels) and since 1750 (inset panels). Measurements are shown from ice cores (symbols with different colours for different studies) and atmospheric samples (red lines). The corresponding radiative forcings are shown on the right hand axes of the large panels. {Figure 6.4}

BIOGRAPHY FOR SUSAN SOLOMON

Susan Solomon is widely recognized as one of the leaders in the field of atmospheric science. Since receiving her Ph.D. degree in chemistry from the University of California at Berkeley in 1981, she has been employed by the National Oceanic and Atmospheric Administration as a research scientist. Her scientific papers have provided not only key measurements but also theoretical understanding regarding ozone destruction, especially the role of surface chemistry. In 1986 and 1987, she served as the Head Project Scientist of the National Ozone Expedition at McMurdo Station, Antarctica and made some of the first measurements there that pointed towards chlorofluorocarbons as the cause of the ozone hole. In 1994, an Antarctic glacier was named in her honor in recognition of that work. In March of 2000, she received the National Medal of Science, the United States' highest scientific honor, for "key insights in explaining the cause of the Antarctic ozone hole." In 2004 she received the prestigious Blue Planet Prize for "pioneering research identifying the causative mechanisms producing the Antarctic ozone hole."

She is the recipient of many other honors and awards, including the J.B. MacElwane award of the American Geophysical Union, the Department of Commerce Gold Medal for Exceptional Service, the Henry G. Houghton and Carl-Gustaf Rossby awards of the American Meteorological Society for excellence in research, the Arthur S. Flemming Award for exceptional government service, the Common Wealth Award of the Common Wealth Trust, and the ozone award from the United Nations Environment Programme. In 1992, *R&D Magazine* honored her as its "scientist of the year." She is a recipient of honorary doctoral degrees from Tulane University, Williams College, the State University of New York at Stony Brook, the Illinois Institute of Technology, the University of Miami, the University of Colorado, and the University of East Anglia in the UK. She is a member of the U.S. National Academy of Sciences and a Foreign Associate of both the French Academy of Sciences and the European Academy of Sciences. Her current research includes climate change and ozone depletion, and she serves as Co-Chair of Working Group I of the Intergovernmental Panel on Climate Change (IPCC), providing scientific information to the United Nations Framework Convention on Climate Change.

Chairman GORDON. Thank you, Doctor. And now Dr. Trenberth.

STATEMENT OF DR. KEVIN E. TRENBERTH, COORDINATING LEAD AUTHOR, IPCC, WORKING GROUP I, CHAPTER 3: OBSERVATIONS: SURFACE AND ATMOSPHERIC CLIMATE CHANGE; HEAD, CLIMATE ANALYSIS SECTION, NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

Dr. TRENBERTH. Thank you, Mr. Chairman. I thank Representative Udall for introducing me, and as he said, I am the Coordinating Lead Author of Chapter 3 of the IPCC Report, which Susan has introduced, and that deals with the observations in the atmosphere and at the surface and also does a synthesis across all observations, and that is what I am going to focus on here.

And essentially, what we have done in the IPCC, perhaps as a medical analogy, is to do a diagnosis of the vital signs of the planet Earth. And what we have found, then, is that the planet is running a fever, so to speak, and the prognosis is that it is apt to become much worse.

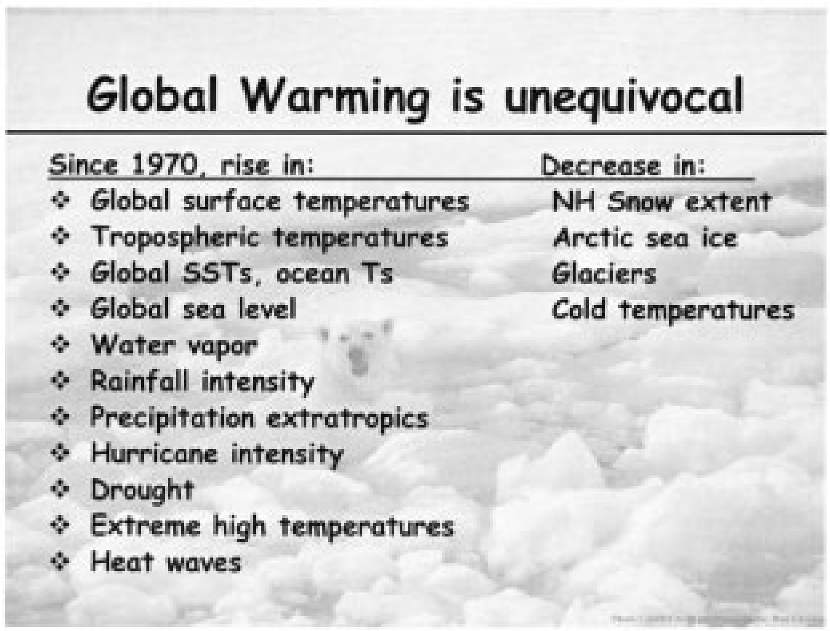
Now to paraphrase the Report, "Warming of the climate system is unequivocal." That is actually a quote, and it is very likely due to human activities.

In my written testimony, a summary is given of the main findings for Chapter 3, and it is linked to the other observational chapters. And the overall summary statement of one of the highlight points in the policy-maker's summary is, to quote, "Warming of the climate system is unequivocal, as is now evident from observations of increases in global-averaged air and ocean temperatures, widespread melting of snow and ice, and rising global mean sea level."

And then there is another item, which goes on to elaborate on more regional aspects and other variables as well. And that is what I am going to focus on in my following remarks.

And so we say that the warming of the climate system is unequivocal because it is now clear from an increasing body of evidence showing discernable, physically-consistent changes. In other words, we can relate all of these changes to warming. And there are many more variables listed than in the brief IPCC statement. Now these include, firstly, global average air temperature, and I am going to come back to that.

If I could have the first slide, if I might, please.



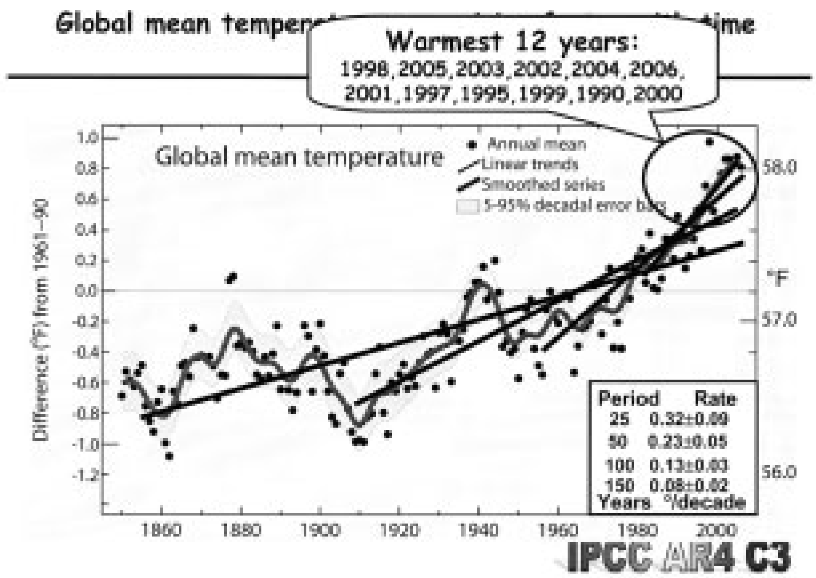
This just shows you global warming is unequivocal, and what I have done here is to put the main bullets that I am going to talk about on here, the different variables and the items.

And so as well as global surface air temperature, there are the air temperatures above the surface, and this refers to what is called often the satellite temperatures. Sea surface temperatures are also increasing, and they are very important for things like storms over the oceans and hurricanes. Subsurface ocean water temperatures are increasing, below the surface. We can measure those, and that leads to expansion of the ocean, contributing to sea level. There is widespread melting of snow in the Northern Hemisphere. There are decreases in Arctic sea ice extent and thickness. There are decreases in glacier and small ice cap extent and mass. And as a result, there is a global mean sea level rise at a rate in the last 12 years of more than a foot a century, and that is contributed to by the expansion of the ocean and the melting of land ice.

The observed surface warming at both global and continental scales is also consistent with the reduced duration of freeze seasons, less frost, increases in heat waves, and increased atmospheric water vapor in the atmosphere, and this is very important, because it feeds into heavier precipitation events, and this includes, ironically, perhaps, heavier snowfall events, because the atmosphere can hold more water vapor when it is warmer.

There are also changes in precipitation around the world, and part of that leads to increases in drought, especially in the tropics, and this is already evident in the observational record. Increases in the intensity of hurricane activity are also evident, and there are changes in the large-scale patterns of atmospheric winds, changes in where storms are actually going in middle latitudes.

So if I can look at the second—or the next slide, here it is here.



This is the global average temperatures, the time series from 1850 up until 2006. The dots are the annual values. The heavy blue curve is the decadal smooth values, and the yellow is the sort of uncertainty around that. And what we frequently do with a curve like this is to put a straight line through it. And if we do that, you get this line here for the last 150 years, and on the bottom right, I don't know if you can see the numbers here, there is actually—the rate of change is given. And what we can also do is then put a line through it for the last 100 years, and it looks like this. And you can see that it is considerably steeper. And then for the last 50 years, it looks like this. And then for the last 25 years, it looks like this. And listed at the top there is a list of the last 12 years. Indeed, 11 out of the last 12 years are the warmest on record.

And so the rate of warming has increased over time, and indeed, this is the direction we are going in the immediate future.

And so the Fourth Assessment Report of IPCC finds that the Earth is warming and that the major components of the Earth's climate system are already responding to that warming.

Now the wide variety of observations gives a very high degree of confidence in the overall findings, and moreover, these changes are now simulated in climate models for the past 100 years to a reasonable degree, as my colleague Jerry Meehl is likely to talk about, and this adds confidence to the future projections.

Mr. Chairman, one interpretation of this is that, you know, as with a fiscal budget, we are running a deficit and building a debt for the future generations. And our current generation is now running what we might refer to as an environmental deficit, and it will, indeed, be paid for by the future generations.

I appreciate the opportunity to address the Committee concerning the science of global climate change, and I look forward to answering any questions.

Thank you.

[The prepared statement of Dr. Trenberth follows:]

PREPARED STATEMENT OF KEVIN E. TRENBERTH

Observations of climate change: The 2007 IPCC Assessment

Summary

Following a detailed diagnosis of the vital signs of the planet Earth, it has become evident that the planet is running a "fever" and the prognosis is that it is apt to get much worse. **"Warming of the climate system is unequivocal" and it is "very likely" due to human activities.** This is the verdict of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), known as AR4. In the following, I provide a brief introduction to the IPCC and its processes. A summary is then given of the main findings from the AR4 for Chapter 3, "Observations: Surface and Atmospheric Climate Change," and its links to other observational chapters. Warming of the climate system is unequivocal as is now clear from an increasing body of evidence showing discernible physically consistent changes. These include increases in global average air temperature; atmospheric temperatures above the surface, surface and sub-surface ocean water temperature; widespread melting of snow; decreases in Arctic sea-ice extent and thickness; decreases in glacier and small ice cap extent and mass; and rising global mean sea level. The observed surface warming at global and continental scales is also consistent with reduced duration of freeze seasons; increased heat waves; increased atmospheric water vapor content and heavier precipitation events; changes in patterns of precipitation; increased drought; increases in intensity of hurricane activity, and changes in atmospheric winds. That is, the IPCC Fourth Assessment finds that the Earth is warming, and that major components of the Earth's climate system are already responding to that warming. This wide variety of observations gives a very high degree of confidence to the overall findings. Moreover these changes are now simulated in climate models for the past 100 years to a reasonable degree, adding confidence to future projections. The summary is followed by a few personal remarks about the meaning of these findings.

Introduction

My name is Kevin Trenberth.[1] I am a senior scientist and the Head of the Climate Analysis Section at NCAR, the National Center for Atmospheric Research.[2] I have authored over 400 publications in the area of climate, and given hundreds of talks on the subject. I am among the most highly cited researchers in all of geophysics. I am especially interested in global-scale climate dynamics; the observa-

[1] Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author and do not necessarily reflect those of the National Science Foundation.

[2] The National Center for Atmospheric Research (NCAR) is sponsored by the National Science Foundation.

tions, processes and modeling of climate changes from inter-annual to centennial time scales. I have particular expertise in El Niño, the hydrological and energy cycles, and hurricanes and climate change. I have served on many national and international committees including National Research Council/National Academy of Science committees, panels and/or boards. I co-chaired the international Climate Variability and Predictability (CLIVAR) Scientific Steering Group of the World Climate Research Programme (WCRP) from 1996 to 1999 and I have served as a member and officer of the Joint Scientific Committee that oversees the WCRP as a whole from 1998 to 2006. I chair the WCRP Observations and Assimilation Panel. I have been involved in global warming science and I have been extensively involved in the Intergovernmental Panel on Climate Change (IPCC) scientific assessment activity as a Lead Author of individual chapters, the Technical Summary, and Summary for Policy-makers (SPM) of Working Group (WG) I for both the Second and Third Assessment Reports (SAR and TAR; IPCC 1996, 2001). I am a Coordinating Lead Author of Chapter 3 of the Fourth IPCC Assessment (AR4) that deals with observations of the surface and atmospheric climate change.

The IPCC is a body of scientists from around the world convened by the United Nations jointly under the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) and initiated in 1988. Its mandate is to provide policy-makers with an objective assessment of the scientific and technical information available about climate change, its environmental and socio-economic impacts, and possible response options. The IPCC reports on the science of global climate and the effects of human activities on climate in particular. Major assessments were made in 1990, 1995, 2001, and now 2007. Each new IPCC report reviews all the published literature over the previous five to seven years, and assesses the state of knowledge, while trying to reconcile disparate claims and resolve discrepancies, and document uncertainties.

WG I deals with how the climate has changed and the possible causes. It considers how the climate system responds to various agents of change and our ability to model the processes involved as well as the performance of the whole system. It further seeks to attribute recent changes to the possible various causes, including the human influences, and thus it goes on to make projections for the future. WG II deals with impacts of climate change, vulnerability, and options for adaptation to such changes, and WG III deals with options for mitigating and slowing the climate change, including possible policy options. Each WG is made up of participants from the United Nations countries, and for the 2007 assessment there are over 450 Lead Authors, 800 contributing authors, and over 2,500 reviewers from over 130 countries. In my chapter, as well as the two Coordinating Lead Authors, we have 10 Lead Authors, 66 contributing authors, about 100 pages of text, 126 figure panels in 47 figures, and 863 references. The IPCC process is very open. Two major reviews were carried out in producing the report, and climate "skeptics" can and do participate, some as authors. For our chapter we received over 2230 comments on the expert review and 1270 on the governmental review, all of which were responded to in writing and by changing the report. The process is overseen by two Review Editors. The strength is that it is a consensus report. The SPM was approved line by line by governments in a major meeting in Paris from 29 January to 1 February, 2007. The rationale is that the scientists determine what can be said, but the governments help determine how it can best be said. Negotiations occur over wording to ensure accuracy, balance, clarity of message, and relevance to understanding and policy. The latest report (IPCC 2007) reaffirms in much stronger language that the climate is changing in ways that cannot be accounted for by natural variability and that "global warming" is happening.

Observed Climate Change

The iconic summary statement of the observations section of the IPCC (2007) report is **"Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global mean sea level."** The language here is carefully chosen to reinforce the view that

1) There are multiple lines of evidence from many variables
2) There is a wide body of evidence and multiple analyses of each variable
3) The variables and evidence are physically consistent with warming
4) The human signal has clearly emerged from noise of natural variability, i.e., it is large.

Since the TAR, progress in understanding how the current climate is changing in space and in time has been gained through improvements and extensions of numerous data sets and data analyses, broader geographical coverage, better understanding of uncertainties, and a wider variety of measurements. Increasingly comprehensive observations are available for glaciers and snow cover since the 1960s, and for sea level and ice sheets since about the past decade. Numerous changes in climate have been observed at the scales of continents or ocean basins. These include wind patterns, precipitation, ocean salinity, sea ice, ice sheets, and aspects of extreme weather.

a. Temperature and related

Instrumental observations over the past 157 years show that temperatures at the surface (Fig. 1) have risen globally, with important regional variations. For the global average, warming in the last century has occurred in two phases, from the 1910s to the 1940s (0.35°C or 0.63°F), and more strongly from the 1970s to the present (0.55°C or 1.0°F) at a rate of about 0.16°C (0.3°F) per decade. An increasing rate of warming has taken place over the last 25 years, and 11 of the 12 warmest years on record have occurred in the past 12 years. Indeed, the six years since the TAR are among the seven warmest years on record. The total warming since the 1800s is about 0.76°C (1.4°F). Globally, 2006 ranks sixth and it was the warmest on record in the United States. Sea surface temperatures (SSTs) are also increasing, however land areas are warming much faster than the oceans since 1970.

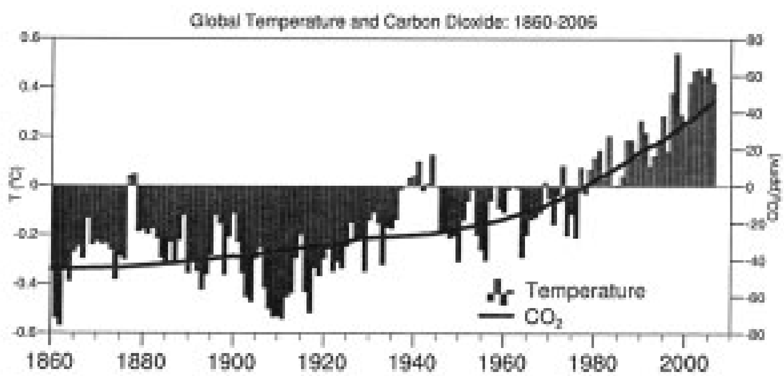


Figure 1. Time series of annual global mean temperature departures for 1861-2006 from a 1961-90 mean (bars), left scale, and the annual mean carbon dioxide from Mauna Loa after 1957 linked to values from bubbles of air in ice cores prior to then. The zero value for 1961-90 for temperature corresponds to 14°C and for carbon dioxide 334 parts per million by volume (ppmv). Updated from Karl and Trenberth (2003).

Two possible issues with the surface temperature record—urban heat island effects, and discrepancies with balloon-based and satellite measurements—have been extensively studied in the 2007 IPCC report. The urban heat island effects are real but local, and have been found to have a negligible influence on the overall surface temperature record. New analyses of balloon-borne and satellite measurements of lower- and mid-tropospheric temperature show warming rates that are similar to the surface temperature record and consistent within their respective uncertainties, largely reconciling a discrepancy noted in the TAR. The 2007 IPCC report essentially removes these two issues as serious sources of uncertainty for the global surface temperature record.

Regional temperature observations do not always track the global average warming because of atmospheric wave patterns, as well as increased natural variability at smaller geographic scales. For example, the eastern half of the United States has not warmed as much as other areas, especially during the daytime, owing to increases in cloud and precipitation associated with changes in atmospheric circulation as the climate changes. On the other hand, average Arctic temperatures increased at almost twice the global average rate in the past 100 years and also since 1960. However, Arctic temperatures have high decadal variability and a warm period was observed from 1925 to 1945, but that was focused in the North Atlantic and not global as in the recent warming.

Since 1950, the number of heat waves globally has increased and widespread increases have occurred in the numbers of warm nights. Cold days, cold nights and frost have generally become rarer.

Decreases are found in the length of the freeze season of river and lake ice. Temperature at the top of the permafrost layer has increased by up to 3°C since the 1980s in the Arctic. The maximum area covered by seasonally frozen ground has decreased by about seven percent in the Northern Hemisphere since 1900 and this value is up to 15 percent in spring.

The average temperature of global ocean water from the surface to a depth of 700m increased significantly from 1961 to 2003, indicating that the ocean is absorbing most of the heat being added to the climate system. This causes seawater to expand and is estimated to have contributed 0.42mm per year to the average sea level rise from 1961 to 2003, and 1.8mm per year from 1993 to 2003.

Sea-ice extents have decreased in the Arctic since 1978, particularly in spring and summer (7.4 percent per decade), and patterns of the changes are consistent with regions showing a temperature increase, although changes in winds are also a major factor. Sea-ice extents were at record low values in 2005, which was also the warmest year since records began in 1850 for the Arctic north of 65 N. There have also been decreases in sea-ice thickness. In contrast to the Arctic, Antarctic sea ice does not exhibit any significant trend since the end of the 1970s, which is consistent with the lack of trend in surface temperature south of 65 S over that period. However, along the Antarctic Peninsula, where significant warming has occurred, progressive break up of ice shelves has occurred beginning in the late 1980s, culminating in the break up of the Larsen-B ice shelf in 2002.

The observed surface temperature increases are consistent with the observed nearly worldwide reduction in glacier and small ice cap mass and extent in the 20th century. In addition, flow speed has recently increased for some Greenland and Antarctic outlet glaciers, which drain ice from the interior, and melting of Greenland has increased after about 2000. Glaciers and ice caps respond not only to temperatures but also to changes in precipitation, and both winter accumulation and summer melting have increased over the last half century in association with temperature increases. In some regions moderately increased accumulation observed in recent decades is consistent with changes in atmospheric circulation and associated increases in winter precipitation (e.g., southwestern Norway, parts of coastal Alaska, Patagonia, and the South Island of New Zealand) even though increased ablation has led to marked declines in mass balances in Alaska and Patagonia. Tropical glacier changes are synchronous with higher latitude ones and all have shown declines in recent decades. Decreases in glaciers and ice caps contributed to sea level rise by 0.5mm per year from 1961 to 2003 and 0.8mm per year from 1993 to 2003. Taken together, shrinkage of the ice sheets of Greenland and Antarctica has contributed 0.4mm per year to sea level rise over 1993 to 2003.

Global average sea level rose at an average rate of 1.8mm per year over 1961 to 2003. The rate was faster during 1993–2003, when truly global values have been measured from altimeters in space, at about 3.1mm per year. Hence about 60 percent of this is from ocean warming and expansion, and 40 percent is from melting land ice, adding to the ocean volume. The observation of consistent sea level rise over several decades, and also an increasing rate of sea level rise in the last decade or so, is probably the single best metric of the cumulative global warming that we have experienced to date. There is really no explanation other than global warming for the observed sea level rise.

The average atmospheric water vapor content has increased over land and ocean as well as in the upper troposphere, and over the global oceans this is estimated to be four percent since 1970. The increase is broadly consistent with the extra water that warmer air can hold and amounts to a fairly constant relative humidity. The added water vapor also adds to the greenhouse effect and roughly doubles that due to carbon dioxide, providing a powerful positive feedback to climate change.

The observed surface warming at global and continental scales is consistent with observed changes in sub-surface ocean water temperature; decreases in sea-ice extent and thickness; decreases in glacier and small ice cap extent and mass; sea-level rise; reduced duration of freeze seasons, increased heat waves; and increased atmospheric water vapor content. That is, the IPCC Fourth Assessment finds that the Earth is warming, and that major components of the Earth's climate system are already responding to that warming. This wide variety of observations gives a very high degree of confidence to the overall findings.

b. Precipitation and related

The 2007 IPCC report finds that changes are occurring in the amount, intensity, frequency, and type of precipitation in ways that are also consistent with a warming planet. These aspects of precipitation generally exhibit large natural variability (compared to temperature trends), and El Niño and changes in atmospheric circulation patterns have a substantial influence, making it harder to detect trends in the observational record.

A key ingredient in changes in character of precipitation is the observed increase in water vapor and thus the supply of atmospheric moisture to all storms, increasing the intensity of precipitation events. Indeed, widespread increases in heavy precipitation events and risk of flooding have been observed, even in places where total amounts have decreased. Hence the frequency of heavy rain events has increased in most places but so too has episodic heavy snowfall events that are thus associated with warming. Snow cover has decreased in many Northern Hemisphere regions, particularly in spring, and more precipitation is falling as rain instead of snow. These changes are consistent with changes in permafrost, noted above.

Long-term trends from 1900 to 2005 have been observed in total precipitation amounts over many large regions. Significantly increased precipitation has been observed in eastern parts of North and South America, northern Europe and northern and central Asia. Drying has been observed in the Sahel, the Mediterranean, southern Africa and parts of southern Asia. Precipitation is highly variable spatially and temporally. Robust long-term trends have not been observed for other large regions. The pattern of precipitation change is one of increases generally at higher northern latitudes (because as the atmosphere warms it holds more moisture) and drying in the tropics and subtropics over land. Basin-scale changes in ocean salinity provide further evidence of changes in the Earth's water cycle, with freshening at high latitudes and increased salinity in the subtropics.

More intense and longer droughts have been observed over wider areas since the 1970s, particularly in the tropics and subtropics. Increased drying due to higher temperatures and decreased precipitation have contributed to these changes, with the latter the dominant factor. The regions where droughts have occurred are determined largely by changes in sea surface temperature (SST), especially in the tropics (such as during El Niño), through changes in the atmospheric circulation and precipitation. In the western United States, diminishing snow pack and subsequent summer soil moisture reductions have also been a factor. In Australia and Europe, direct links to warming have been inferred through the extreme nature of high temperatures and heat waves accompanying drought.

Satellite records suggest a global trend towards more intense and longer lasting tropical cyclones (including hurricanes and typhoons) since about 1970, correlated with observed warming of tropical SSTs. There is no clear trend in the annual number of tropical cyclones globally although a substantial increase has occurred in the North Atlantic after 1994. There are concerns about the quality of tropical cyclone data, particularly before the satellite era. Further, strong multi-decadal variability is observed and complicates detection of long-term trends in tropical cyclone activity.

c. Synthesis across variables

In summary, global mean temperatures have increased since the 19th century, especially since the mid-1970s. Temperatures have increased nearly everywhere over land, and SSTs have also increased, reinforcing the evidence from land. However, global warming does not mean that temperatures increase steadily or uniformly, indeed temperatures have increased neither monotonically, nor in a spatially uniform manner, especially over shorter time intervals. The atmospheric circulation has also changed: in particular increasing westerly wind flow is observed in most seasons in both hemispheres. In the Northern Hemisphere this brought milder maritime air into Europe and much of high-latitude Asia from the North Atlantic in winter, enhancing warming there. In the Southern Hemisphere, where the ozone hole has played a role, it has resulted in cooling over 1971–2000 for parts of the interior of Antarctica but large warming in the Antarctic Peninsula region and Patagonia. Temperatures generally have risen more than average where flow has become more poleward, and less than average or even cooled where flow has become more equatorward, reflecting atmospheric patterns of variability.

Over land in low latitudes and in summer more generally, there is a strong tendency for either hot and dry or cool and wet. Hence areas that have become wetter, such as the eastern United States and Argentina, have not warmed as much as other land areas. Increased precipitation is associated with increases in cloud and surface wetness. Thus more heat goes into increased evapotranspiration and less into raising temperature at the surface in wetter conditions.

The three main ocean basins are unique and contain very different wind systems, SST patterns and ocean currents, leading to vastly different variability associated, for instance, with El Niño in the Pacific, and the ocean currents including the Gulf Stream in the Atlantic. Consequently the oceans have not warmed uniformly, especially at depth. SSTs in the tropics have warmed at different rates and help drive, through coupling with tropical convection and winds, distinctive wave patterns known as teleconnections around the world. This has changed the atmospheric circulation and the monsoons. Changes in precipitation and storm tracks are not as well documented but clearly respond to these changes on inter-annual and decadal timescales. When precipitation increases over the ocean, as it has in recent years in the tropics, it decreases over land, although it has increased over land at higher latitudes. Droughts have increased over many tropical and mid-latitude land areas, in part because of decreased precipitation over land since the 1970s but also from increased drying arising from increased atmospheric demand associated with warming.

Many of these observed changes are now simulated in climate models run for the past 100 years, adding confidence to understanding of the relationship with the agents that alter the climate, and human-induced changes in atmospheric composition, in particular, as is documented in other IPCC chapters.

Some implications

The scientific understanding of climate change is now sufficiently clear to show that specific global and regional changes resulting from global warming are already upon us. Uncertainties remain, and new efforts at reprocessing past satellite records for phenomena such as hurricanes are required, but the 2007 IPCC report definitively shows that the climate is changing. "Warming is unequivocal" and it is "very likely" caused by human activities.

In my personal opinion as a climate scientist, the IPCC report strongly implies the need for a three pronged approach of mitigation, adaptation, and maintaining and improving climate observing and information systems.

While there are uncertainties (although these cut both ways) and some changes arising from global warming may be benign or even beneficial, at least in some places and in the short run, the IPCC report shows that the rate of change as projected exceeds anything seen in nature in the past 10,000 years. Moreover, the inertia of the climate system and the long life of carbon dioxide in the atmosphere mean that we are already committed to a significant level of climate change. I believe that mitigation actions are certainly needed to significantly reduce the build-up of greenhouse gases in the atmosphere and lessen the magnitude and rate of climate change.

At the same time, the 2007 IPCC report makes clear that even aggressive mitigation would yield benefits many decades in the future, and that no amount of mitigation can avoid significant climate change. I believe it is apt to be disruptive in many ways. Hence it is also vital to plan to cope with the changes, such as enhanced droughts, heat waves and wild fires, and stronger downpours and risk of flooding. Managing water resources will be a major challenge in the future. Adapting to climate change and reducing vulnerability is essential. This means that we should adapt to climate change by planning for it and making better predictions of likely outcomes on several time horizons.

Finally, although not reported by the IPCC, my experience in working with observations of climate change has led me to urge the Committee to address the considerable shortcomings in our observing systems. Weather observing systems are continually used for climate purposes for which they were not designed. Moreover, weather stations come and go and changes are made without regard to the effect on the climate record. Changes in observing systems, especially from satellites, as new satellites and instruments are launched, create artifacts in the climate record. Loss of Earth observing satellites is also of concern, as documented in the recent National Research Council (2007) decadal survey. Ground based observations are not being adequately kept up in many countries. Calibration of climate records is critical. Small changes over long times are characteristic of climate change but they occur in the midst of large variations associated with weather and natural climate variations such as El Niño. Yet the climate is changing and an imperative is to track the changes and the causes as they occur. We need to build a system based on these observations to inform decision-makers on what is happening, and why, and what the predictions are for the future on several time horizons.

I appreciate the opportunity to address the Committee concerning the science of global climate change, and look forward to answering any questions you may have today or in the future.

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BIOGRAPHY FOR KEVIN E. TRENBERTH

Dr. Kevin Trenberth is Head of the Climate Analysis Section at the National Center for Atmospheric Research (NCAR) in Boulder, CO. From New Zealand, he completed a first class honors degree in mathematics at the University of Canterbury, Christchurch, New Zealand, and obtained his Sc.D. in meteorology in 1972 from Massachusetts Institute of Technology, Cambridge, Massachusetts. He was previously employed as a research scientist in the New Zealand Meteorological Service and was a Professor at the University of Illinois for nearly seven years prior to joining NCAR in 1984.

He was named a Fellow of the American Meteorological Society (AMS) in 1985, the American Association for Advancement of Science (AAAS) in 1994, the American Geophysical Union in 2006 and an Honorary Fellow of the New Zealand Royal Society in 1995. In 2000 he received the Jule G. Charney award from the AMS and in 2003 he was given the NCAR Distinguished Achievement Award. He has served as an editor and associate editor for several professional journals. He edited a 788 page book, *Climate System Modeling* (1992). He has published over 400 scientific articles or papers, including 40 books or book chapters, and over 175 refereed journal articles and has given many invited scientific talks as well as appearing in a number of television, radio programs and newspaper articles. He is listed among the top 20 authors in highest citations in all of geophysics.

Trenberth has served on a number of national and international advisory committees and panels including many panels, committees and a board of the National Academy of Sciences. Trenberth has been prominent in the Intergovernmental Panel on Climate Change (IPCC) Scientific Assessment activities, was a Convening Lead Author for the 1995 Scientific Assessment and Lead Author for the 2001 assessment (including for the Technical Summary and Summary for Policy-makers) and is a Coordinating Lead Author of the 2007 assessment. He has recently served as a member of the National Oceanic and Atmospheric Administration (NOAA) Climate Working Group (from 1987 to 2006), and is a member of NOAA's Climate Observing System Council, and NOAA's Advisory Panel for Climate Change Data and Detection. He also recently served on the Joint Scientific Committee of the World Climate Research Programme (WCRP) from 1999 to 2006 and was an officer from 2003 to 2006, and he chairs the WCRP Observations and Assimilation Panel. He served on the Scientific Steering Group for the WCRP Climate Variability and Predictability (CLIVAR) program and was Co-Chair from 1995 to 1999.

See *http://www.cgd.ucar.edu/cas/trenbert.html*

Chairman GORDON. Dr. Alley.

STATEMENT OF DR. RICHARD B. ALLEY, LEAD AUTHOR, IPCC, WORKING GROUP I, CHAPTER 4: OBSERVATIONS: CHANGES IN SNOW, ICE AND FROZEN GROUND; EVAN PUGH PROFESSOR OF GEOSCIENCES AND ASSOCIATE OF THE EARTH AND ENVIRONMENTAL SYSTEMS INSTITUTE, PENNSYLVANIA STATE UNIVERSITY

Dr. ALLEY. Thank you, Mr. Chairman, honored Members.

As Dr. Trenberth pointed out, observations of snow and ice show that melting is now widespread. We see this in snow cover in the north. We see this in the Arctic sea ice. We see it in most of the glaciers of the world. We see it in frozen ground and permafrost. We see it in the great ice sheets of Greenland and Antarctica. And we see it even where there is more snow falling. And so it is really hard to blame a loss of ice on loss of snow if there is more snow in some places, and yet it is melting faster. And so it is very clear that warming is implicated in this.

I would like to focus especially on the large ice sheets of Greenland and Antarctica, because they have great potential to change sea level. Snow falls on top, melting happens around the side, especially in Greenland, and our understanding of those processes has gotten a lot better. However, we have observed surprising changes in the flow of the ice sheets around their edges that we didn't really expect.

If I may, for a moment, an ice sheet is just a two-mile-thick, continent-wide pile of snow that has been squeezed to ice under its own weight. And like any pile, it spreads under its own weight. If I were to pour pancake batter on a griddle in front of us here, you would see it spread and thin and drip off the edge. The same thing happens to an ice sheet. It spreads and thins and it drips icebergs off of the edge.

If I were to grease that pancake griddle, you would see the batter spread faster. Ice sheets have exactly the same problem. In Greenland, observations show that when the melt water starts on the edge, it goes through great holes in the ice to the bottom, and water makes things slippery. And so the ice actually spreads faster because of this melt water that amplifies the effects of it. And so in the same way that you can grease a pancake griddle, the ice sheet is greasing its own bed to spread faster.

If I were holding the pancake batter in with a spatula and I removed it, of course, the batter would spread faster, and ice sheets have this same problem, as well. When the ice gets down to the ocean, it usually does not immediately break off to make an iceberg. It spreads over the ocean in something we call an ice shelf, and that will run aground on an island, or it will sheer past the rocky sides of a fjord, and those hold back in the same way that your spatula holds back the spreading pancake batter.

Now in a warming world, those are very low in elevation. They can be warmed easily. They are in contact with the ocean already. They are at the melting point underneath, and so they can melt very easily underneath. We have seen where warming has attacked these spatulas, these ice shelves, and when they have been pulled out of the way, the ice behind is gone faster by as much as eightfold. So we know these things are out there, and we know that we don't have a really good scientific understanding of all of these aspects. And when we look to the future, we expect sea level to rise, as ocean water warms and expands, as the mountain glaciers melt, and with effects from changing snowfall and melting on the big ice sheets.

And there is a greatly increased confidence in that. If you compare the projections of sea level rise that were just now made in the new Report to those that were made in the previous report, we have a better understanding of certain things. The numbers have looked slightly different. Had we treated uncertainties in exactly the same way, you would have had very similar projections. They have not changed much. But we have this additional uncertainty that we just don't know whether these changes in the spreading of that giant pile in Antarctica or that giant pile in Greenland will slow down, whether they will stay constant, whether they will speed up. It is just this big uncertainty that is sitting out there.

We do not have any credible scientific models of which I personally am aware that would dump an ice sheet into the ocean over decades. However, it is possible that we will reach temperatures over decades that, if sustained, would lose an ice sheet over centuries to millennia. As someone who works for a land grant institution, which tries to provide useful advice to you, I am distressed that I cannot tell you more accurately what the future might hold. As someone who gets paid to do research, I am really excited. I am going to go home and have fun.

So to summarize, we have much scientific confidence that warming-induced ice loss is now widespread in the climate system, that it is contributing to sea level rise and other changes. Improved understanding of many aspects of this is reflected in the new Report, and it is really wonderful, but there are unexpected changes in ice flow that have occurred for which we lack a scientific basis to provide accurate estimates.

Thank you.

[The prepared statement of Dr. Alley follows:]

PREPARED STATEMENT OF RICHARD B. ALLEY

Changes in Ice:
The 2007 IPCC Assessment

Introduction

My name is Richard Alley.[1] I am Evan Pugh Professor of Geosciences and Associate of the Earth and Environmental Systems Institute at the Pennsylvania State University. I have authored over 170 refereed scientific publications in the areas of ice and climate, which are "highly cited" according to a prominent indexing service, and I have given hundreds of presentations concerning my areas of expertise. My research interests focus especially on glaciers and ice sheets, their potential for causing major changes in sea level, and the climate records they contain. I have been a member of many national and international committees, including chairing the National Research Council's Panel on Abrupt Climate Change and serving on their Polar Research Board. I have contributed to the efforts of the Intergovernmental Panel on Climate Change (IPCC) in various ways, and serve as a Lead Author on Chapter 4 (the Cryosphere), and on the Technical Summary and the Summary for Policy-makers of Working Group I of the Fourth Assessment Report. A

[1] Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author and do not necessarily reflect those of the Pennsylvania State University, the Intergovernmental Panel on Climate Change, or other organizations.

brief description of the IPCC process as it applies to this testimony is appended, for your information.

Changes in Ice

The newly released report reaffirms the strong scientific evidence that human activities are changing the composition of the planet's atmosphere, and that this is warming the climate and affecting it in other ways. In particular, our chapter documents the increasingly strong evidence for widespread reductions in the Earth's ice, including snow, river and lake ice, sea ice, permafrost and seasonally frozen ground, mountain glaciers, and the great ice sheets of Greenland and Antarctica. Our chapter and others highlight the strong evidence for the dominant role of warming, which is primarily being caused by human activities, in this loss of ice.

I will briefly summarize some of these many aspects, especially focusing my attention on the issue of ice-sheet shrinkage and its possible effect on sea-level rise. I will rely on the recent IPCC report, as well as other materials as needed.

Snow cover has decreased in most regions, as shown by satellite data tied to limited surface observations. Snow melt is shifting earlier into the spring. Declines in April 1 snowpack have been measured in 75 percent of western North American sites monitored. Impacts of climate change on people will be covered in the WGII report, coming soon, but other sources express great concern about earlier snowmelt in the U.S. West, because the snow pack in many regions is a dominant source of summertime water. Trends in snow cover cannot be explained by changing precipitation (and indeed, in some very cold places snow depth has increased with increasing precipitation), but the overall shrinkage of snow cover can be explained by rising temperature.

Freezing of rivers and lakes generally has been occurring later in the fall, with thawing earlier in the spring, giving longer intervals of open water. Coordinated data collection is scarce, however, and the data set not extensive.

Arctic sea ice, formed by freezing of ocean water, has decreased in area and thickness. The change in the summer has been especially large, with ice lost from an area twice the size of Texas between 1979 and 2005 (decreasing trend in ice area of seven percent per decade over that interval). Data sets from satellites, tied to observations from ships submarines, have been especially important in documenting these changes. Although shifts in circulation of the ocean and atmosphere may have contributed to the ice loss, greenhouse-gas warming is likely to have been important. (Any Antarctic sea-ice changes fall within natural variability; cooling associated with the ozone hole may be affecting Antarctic climate, a complex subject beyond the scope of these brief remarks.)

Permanently frozen ground (permafrost) and seasonally frozen ground are not readily monitored globally. However, available reports point to overall warming and thawing of this ice in the ground, in response to rising air temperatures and changes in snow cover.

Glaciers and ice caps occur primarily in mountainous areas, and near but distinct from the Greenland and Antarctic ice sheets. On average, the world's glaciers were not changing much around 1960 but have lost mass since, generally with faster mass loss more recently. Glacier melting contributed almost an inch to sea-level rise during 1961–2003 (about 0.50 mm/year, and a faster rate of 0.88 mm/year during 1993–2003). Glaciers experience numerous intriguing ice-flow processes (surges, kinematic waves, tidewater instabilities), allowing a single glacier over a short time to behave in ways that are not controlled by climate. Care is thus required when interpreting the behavior of a particular iconic glacier (and especially the coldest tropical glaciers). But, ice-flow processes and regional effects average out if enough glaciers are studied for a long enough time, allowing glaciers to be quite good indicators of climate change. Furthermore, for a typical mountain glacier, a small warming will increase the mass loss by melting roughly five times more than the increase in precipitation from the ability of the warmer air to hold more moisture. Thus, glaciers respond primarily to temperature changes during the summer melt season. Indeed, the observed shrinkage of glaciers, contributing to sea-level rise, has occurred despite a general increase in wintertime snowfall.

Ice-sheet Changes

The large ice sheets of Greenland and Antarctica are of special interest, because they are so big and thus could affect sea level so much. Melting of all of the world's mountain glaciers and small ice caps might raise sea level by about one foot (0.3m), but melting of the great ice sheets would raise sea level by just over 200 feet (more than 60m). We do not expect to see melting of most of that ice, but even a relatively small change in the ice sheets could matter to the world's coasts.

A paper published in the journal *Science* last week (Rahmstorf et al., 2007) compared the projections made in the 2001 IPCC Third Assessment Report to changes that have occurred. The carbon dioxide in the atmosphere has followed expectations closely. Temperature has increased just slightly faster than projected, but well within the stated uncertainties. Sea level is following near the upper edge of the stated uncertainties, however, well above the central estimate. Changes in the ice sheets help explain this.

The 2001 IPCC report noted large uncertainties, but presented a central estimate that the combined response of the ice sheets to warming would be net growth, lowering the sea-level rise from other sources averaged over the 21st century, with increase in snowfall on the ice sheets exceeding increase in melting and with little change in ice flow. Data collected recently show that the ice sheets very likely have been shrinking and contributing to sea level rise over 1993–2003 and with even larger loss by 2005, as noted in the IPCC report and elsewhere (e.g., Alley et al., in press; Cazenave, 2006). Thickening in central Greenland from increased snowfall has been more than offset by increased melting in coastal regions. Many of the fast-moving ice streams that drain Greenland (see the Figure, below) and parts of Antarctica have accelerated, transferring mass to the ocean and further contributing to sea-level rise. The total contribution to sea-level rise from the ice sheets remains smaller than the contribution from mountain-glacier melting or from the expansion of ocean water as it warms. However, the existence of the ice-sheet contribution, its important ice-flow source, and the large potential sea-level rise from such mechanisms in the future motivate careful consideration.

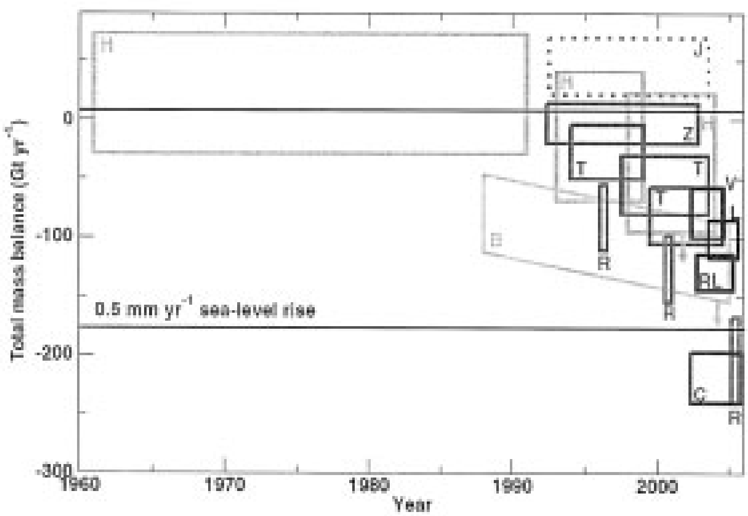
An ice-sheet is a two-mile-thick, continent-wide pile of snow that has been squeezed to ice. All piles tend to spread under their own weight, restrained by their own strength (which is why spilled coffee spreads on a table top but the stronger table beneath does not spread), by friction beneath (so pancake batter spreads faster on a greased griddle than on a dry waffle iron), or by "buttressing" from the sides (so a spatula will slow the spreading of the pancake batter). Observations at a site in Greenland have shown that meltwater on top of the ice sheet flows through the ice to the bottom and reduces friction there. More melting in the future thus may reduce friction further, speeding the production of icebergs and the increase in sea level.

Some early gothic cathedrals suffered from the "spreading-pile" problem, the sides tending to bulge out while the roof sagged down, with potentially unpleasant consequences. The beautiful solution was the flying buttress, which transfers some of the spreading tendency to the strong Earth beyond the cathedral. Ice sheets also have flying buttresses, called ice shelves. The ice reaching the ocean usually does not immediately break off to form icebergs, but remains attached to the ice sheet while spreading over the ocean. The friction of these ice shelves with islands, or with the sides of embayments, helps restrain the spreading of the ice sheet much as a flying buttress supports a cathedral. The ice shelves are at the melting point where they contact water below, and are relatively low in elevation hence warm above. Ice shelves thus are much more easily affected by climatic warming than are the thick, cold central regions of ice sheets. Rapid melting or collapse of several ice shelves has occurred recently, allowing the "gothic cathedrals" behind to spread faster, contributing to sea-level rise.

Although science has succeeded in generating useful understanding and models of numerous aspects of the climate, similar success is not yet available for ice-sheet projections, for reasons that I would be happy to explore with the Committee. We do not expect ice sheets to collapse so rapidly that they could raise sea level by meters over decades; simple arguments point to at least centuries. However, the IPCC report is quite clear on the lack of scientific knowledge to make confident projections.

Synopsis

In summary, with high scientific confidence, changes are occurring in much of the world's ice. These are being caused primarily by warming. That warming is largely being caused by greenhouse gases being released to the atmosphere by human activities. Shrinkage of the large ice sheets was unexpected to many observers but appears to be occurring, and the poor understanding of these changes prevents reliable projections of future sea-level rise over long times.



Recently published estimates of the mass balance of the Greenland ice sheet through time (Alley et al., in press)

A Total Mass Balance of 0 indicates neither growth nor shrinkage, and -180 Gt yr-1 indicates ice-sheet shrinkage contributing to sea-level rise of 0.5 mm/year (one inch in about 50 years), as indicated. Each box extends from the beginning to the end of the time interval covered by the estimate, with the upper and lower lines indicating the uncertainties in the estimates. A given color is associated with a particular technique, and the different letters identify different studies. Two estimates have arrows attached, because those authors indicated that the change is probably larger than shown. The dotted box in the upper right is a frequently-cited study that applies only to the central part of the ice sheet, which is thickening, and misses the faster thinning in the margins.

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Rahmstorf, S., A. Cazenave, J.A. Church, J.E. Hansen, R.F. Keeling, D.E. Parker and R.C.J. Somerville. 2007. Recent observations compared to projections. *Science,* Sciencexpress, 10.1126/science.1136843.

The Intergovernmental Panel on Climate Change (IPCC) Assessment

The IPCC was founded by the United Nations Environment Programme and the World Meteorological Organization in 1988 (this information is summarized from the publications of the IPCC, which are widely available including at *www.ipcc.ch*). The Panel is charged to assess the best scientific information on climate change, in a comprehensive, objective, open and transparent way. The panel is divided into three working groups. Working Group I assesses the scientific aspects of the climate system and climate change. Working Group II assesses the vulnerability of socio-economic and natural systems to climate change, negative and positive consequences of climate change, and options for adapting to it. Working Group III assesses options for limiting greenhouse gas emissions and otherwise mitigating climate change.

The IPCC reports are written by teams of authors, who are nominated by governments and international organizations. Author selection is based on expertise relative to the specific task. Experts come from universities, research centers, business and environmental associations, and other organizations from more than 130 countries. Procedures are enforced to ensure that the results of the IPCC process are policy-relevant. A rigorous review process is used throughout the process. Specialists review a first draft of the report, and governments, authors and independent experts review a second draft, with special review editors for each chapter ensuring that balance is maintained and that all review comments are properly addressed. For our chapter, Chapter 4 (the Cryosphere) of Working Group I of the Fourth Assessment Report, which in near-final draft had 47 pages, 255 references, and 23 figures involving 41 panels, the two Coordinating Lead Authors, nine Lead Authors (informed by 44 contributing authors), and two review editors addressed over 1,000 comments from the expert review alone. As one of the shorter chapters, we were not the busiest. The Third Assessment Report in total involves more than 2,500 expert reviewers, 800 contributing authors, and 450 Lead Authors.

The report from Working Group I was condensed into a Technical Summary, and then into a Summary for Policy-makers. The Summary for Policy-makers was approved line-by-line by governments in plenary from January 29 to February 1 in Paris, and was released to the public on February 2, 2007. The Technical Summary and the full report will follow later in the spring, as will reports from Working Groups II and III. The approximately 1,000-page main report from Working Group I is being copy-edited and formatted for publication, with a limited number of small changes in specific wording for clarity based on the results of the Paris plenary.

BIOGRAPHY FOR RICHARD B. ALLEY

Dr. Richard Alley is Evan Pugh Professor of Geosciences and Associate of the Earth and Environmental Systems Institute at The Pennsylvania State University, University Park, where he has worked since 1988. He was graduated with the Ph.D. in 1987 from the University of Wisconsin–Madison and with M.Sc. (1983) and B.Sc. (1980) degrees from The Ohio State University–Columbus, all in Geology. Dr. Alley teaches, and conducts research on the climatic records, flow behavior, and sedimentary deposits of large ice sheets, to aid in prediction of future changes in climate and sea level. His experience includes three field seasons in Antarctica, eight in Greenland, and three in Alaska. His awards include the Seligman Crystal of the International Glaciological Society, the first Agassiz Medal of the European Geosciences Union Cryospheric Section, a Presidential Young Investigator Award, the Horton Award of the American Geophysical Union Hydrology Section and Fellowship in the Union, the Wilson Teaching Award and the Mitchell Innovative Teaching Award of the College of Earth and Mineral Sciences and the Faculty Scholar Medal in Science at Penn State. Dr. Alley has served on a variety of advisory panels and steering committees, including chairing the National Research Council's Panel on Abrupt Climate Change, and has provided requested advice to numerous government officials in multiple administrations including a U.S. Vice President, the President's Science Advisor, and a Senate Committee. He has published over 170 refereed papers, and is a "highly cited" scientist as indexed by ISI. His popular account of climate change and ice cores, *The Two-Mile Time Machine,* was chosen science book of the year by Phi Beta Kappa in 2001. Dr. Alley is happily married with two children, two cats, and two bicycles, and resides in State College, PA, where he coaches recreational soccer and occasionally plays some.

Chairman GORDON. Thank you, Dr. Alley.

I just received a message here that the International House of Pancakes wanted to offer you an evening job if you need to supplement. I know that land grant institutions don't pay that well.

Dr. Meehl.

STATEMENT OF DR. GERALD A. MEEHL, COORDINATING LEAD AUTHOR, IPCC, WORKING GROUP I, CHAPTER 10: GLOBAL CLIMATE PROJECTIONS; SENIOR SCIENTIST, NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

Dr. MEEHL. Yes. Dr. Alley's enthusiasm is, indeed, contagious. I think we would all like to run back to our labs and get back to work on science after doing a lot of this kind of assessment work.

But I want to thank the Chairman and Members of the Committee for the opportunity to communicate to you some of the findings from the IPCC AR4.

The thing I wanted to stress, the first thing, is that a significant new aspect regarding projections of future climate change has involved an unprecedented coordinated international effort to perform a set of climate change experiments. These were done with high-end computer climate modeling tools we use to quantify possible future climate change. These are called Global-Coupled Ocean and Atmosphere Climate Models, or we just call them AOGCMs for short, and a total of 16 modeling groups from around the world from 11 countries, and this includes three groups in the United States, use 23 of these high-end models, AOGCMs, to perform coordinated climate-change experiments. These include simulations of 20th century climate with both natural and anthropogenic forcings, three possible outcomes for the 21st century based on low, medium, and high emission scenarios and three idealized stabilization experiments.

These data were then collected and made openly available for analysis, and this is really the first time we have been able to do something on this scale. And to date, over 950 scientists from around the world have accessed these model data. And the many papers that have been written were assessed by us in the process of coming up with the AR4. These analyses provide an improved quantification of likelihoods and many aspects of future climate change.

And a little more on the models, the amount of detail and realism in the climate models we use has increased in recent years. This is partly because of our increase in understanding of the processes in the climate system and also in part because the calculations provided by newer supercomputers has increased.

For future climate, this now allows us to provide more detailed information on aspects of the climate system, such as possible future changes of weather and climate extremes.

Regarding near-term climate change, warming of about two-tenths of a degree centigrade per decade over the next couple of decades is projected across the range of scenarios considered. And this actually continues about the same rate we have observed in observations over the past few decades.

Hypothetically, if concentrations of greenhouse gases had been held constant at year 2000 values, we are already committed to about a tenth of a degree C per decade, mainly due to the slow response of the ocean. By the 2020s, most of the United States is projected to warm by about an additional one degree centigrade, and this is larger than warming we observed during the 20th century and very likely larger than estimates of natural variability during the 20th century.

As we approach the middle part of the 21st century and beyond, it is clear that it makes a difference regarding what emission scenario we choose to follow now. By 2100, there is a spread of globally-averaged surface air temperature increase among the six scenarios considered. Best estimates for this global warming range from about 1.8 degrees centigrade for the lowest scenario with a likely range of 1.1 to 2.9 degrees C and four degrees C for the highest scenario with a likely range of 2.4 degrees to 6.4 degrees centigrade.

Now these scenarios are constructed based on various assumptions of future population growth, economic activity, and energy usage, but no climate initiatives were considered in these scenarios.

So based on the existing models available for assessment, the central values for projection of sea level rise by 2100 are similar to previous estimates. These range from about 20 to 40 centimeters, depending on scenario, with the upper end of the range for the highest scenario of about 60 centimeters. These ranges of sea level rise are narrower than previous estimates, mainly because of reduced uncertainties in some of the components that contribute to sea level rise.

However, a large unquantified uncertainty arises from processes we don't yet fully understand and have only recently been able to observe, such as potential ice sheet instability that Dr. Alley was alluding to.

For example, additional sea level rise from this source by the end of the 21st century could add another 10 to 20 centimeters to the upper ranges and higher future sea level rise values cannot be excluded. This is an area of great concern and active ongoing research given the potential consequences.

As seen in recent trends and observations, the future pattern for temperature change is characterized by greater warming over land compared to oceans and more warming at high northern latitudes. Associated with these temperature changes there are projected decreases of snow cover, decreases in thaw depth over most permafrost regions and other changes. Reductions in sea ice, of course, go along with increased temperatures with a late summer sea ice free Arctic by the end of the 21st century in the high forcing scenario in some models. The pattern of future precipitation change indicates increases at higher latitudes, such as the northern tier of states during winter and decreases over subtropical land areas, such as the Southwest United States.

Though the picture of a future warming world appears bleak, it is not yet hopeless. The six different mission scenarios considered in the AR4 show that the longer we wait to do something, the worse the problem gets. These scenarios also illustrate that what we do now can make a difference for the future.

Thank you very much for your invitation to address the Committee.

[The prepared statement of Dr. Meehl follows:]

PREPARED STATEMENT OF GERALD A. MEEHL

Global Climate Projections: The 2007 IPCC Assessment

Introduction

I thank the Chairman and other Members of the Committee for the opportunity to communicate to you today some of the recent findings from the IPCC Fourth Assessment Report (AR4). My name is Gerald Meehl, Senior Scientist at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado. My research interests include tropical climate involving the monsoons and El Niño Southern Oscillation, climate variability and climate change. I have authored or co-authored more than 145 peer-reviewed scientific journal articles and book chapters. I have been involved with the Intergovernmental Panel on Climate Change (IPCC) assessments since the first one that was published in 1990. I was a Contributing Author on that first assessment and its update in 1992, a Lead Author for the 1995 Assessment, and a Coordinating Lead Author for the 2001 and the present 2007 assessments. I have been involved with committees of the World Climate Research Program (WCRP) on Climate Variability and Predictability (CLIVAR), and am currently Co-

Chair of the WCRP/CLIVAR Working Group on Coupled Models (WGCM). This committee organized and coordinated the international modeling groups in performing climate model experiments for assessment in the AR4, and in the collection and analysis of data from those model experiments. Through the efforts of that committee, this extensive multi-model data set on climate change has been made openly available for analysis, and over 950 scientists from around the world have been able to access and analyze these data. The resulting papers have contributed extensively to the IPCC AR4. I have served on several National Research Council (NRC) panels, and am currently a member of the NRC Climate Research Committee. I was a Lead Author on the U.S. Climate Change Science Program (CCSP) Report 1.1 on temperature trends in the atmosphere, and am currently co-coordinator for the CCSP report on weather and climate extremes in a changing climate.

In my capacity as a Coordinating Lead Author for the chapter on climate change projections for the IPCC AR4, I was in Paris last week attending the Plenary of the IPCC where the IPCC Fourth Assessment Report was accepted and approved by the roughly 180 governments that make up the IPCC. Thus, the IPCC is a group of governments, not a group of scientists, which is a common misconception. The IPCC commissions assessments to be performed roughly every five or six years, and they are prepared through the efforts of hundreds of scientists from around the world who are actively involved in state-of-the-art research in climate science. The IPCC assessments provide a comprehensive view of the current state of human understanding of climate science and climate change. My testimony today will summarize some of the main findings of the IPCC AR4 with regards to projections of future climate change.

A much larger group of climate models have contributed to the IPCC AR4

A major international effort to perform a set of coordinated climate change experiments was organized by the WCRP/CLIVAR WGCM. A total of 16 modeling groups from 11 countries (three groups from the U.S.) used 23 global coupled climate models to perform these coordinated climate change experiments that involved simulations of the 20th century climate, three possible outcomes for the 21st century (based on low, medium and high emission scenarios), and three idealized stabilization experiments. In addition there were idealized carbon dioxide increase experiments, and associated stabilization experiments with doubled and quadrupled CO_2 amounts. These data were then collected, and over 31 Terabytes of model data were archived at the DOE-sponsored Program for Climate Model Diagnosis and Intercomparison (PCMDI) at Lawrence Livermore National Lab (LLNL) in Livermore, CA. WGCM then coordinated the analysis of this multi-model data set. This unprecedented effort has involved over 950 scientists who have accessed these model data and wrote many papers that were assessed in the AR4. This massive effort was the first time the international climate modeling community has performed such an extensive set of climate change experiments, with the output from those experiments openly available for analysis.

Climate change commitment and near-term warming

Several of the experiments run with the most recent global climate models explored the concept of climate change commitment. That is, if concentrations of greenhouse gases are stabilized at various levels, how much more warming would occur due to the emissions already in the system. Such committed climate change is due to the time lag introduced by the oceans because it takes longer for water to warm. If concentrations of greenhouse gases could have been stabilized in the year 2000, a committed warming of about 0.1C per decade averaged over the period 2000 to 2020 would occur, with smaller warming continuing after that. Of course there are ongoing increases of greenhouse gases, so the models project that no matter what emissions scenario is followed (not taking into account possible large volcanic eruptions that we are not able to forecast but would produce temporary cooling a year or two after the eruption), the combination of climate change commitment and additional warming from increasing greenhouse gases would result in a warming of about 0.2C per decade over the next two decades.

The sea level rise commitment is much longer-term. This is due to the effects of thermal expansion on sea level. That is, since water has the physical property of expanding as it heats up, as the warming penetrates deeper into the ocean, an ever increasing volume of water expands and contributes to ongoing sea level rise. Since it would take centuries for the entire volume of the ocean to warm in response to the effects of the greenhouse gases we have already put into the air, we are committed right now to further sea level rise that would continue for centuries.

Previous IPCC assessments starting in 1990 used global climate models to project global warming of between about 0.15C and 0.3C per decade for 1990 to 2005. The actual observed values of global warming for that time period are about 0.2C per decade. This increases our confidence in the climate model projections for future climate change, since previous generations of models were able to project warming rates similar to those subsequently observed.

Climate change later in the 21st century

As we approach the middle part of the 21st century and beyond, it makes a difference regarding what emissions scenario we choose to follow now. By 2100 there is a spread of globally averaged surface air temperature increase among the six scenarios considered, with best estimates ranging from nearly 2C for a lowest scenario (B1) and about 4C for the highest scenario (A1FI). Likely ranges for warming at the end of the 21st century are also now provided. For example, for a low scenario (B1), the warming averaged for 2090–99 relative to 1980–99 has a best estimate of 1.8C with a likely range of 1.1C to 2.9C. For a medium scenario (A1B), the best estimate is 3.4C with a likely range of 2.0C to 5.4C, and for the highest scenario (A1FI), the best estimate is 4.0C with a likely range from 2.4C to 6.4C. There are greater values at the higher end of the ranges due to relatively new understanding regarding the nature of the feedbacks from the carbon cycle (i.e., how the oceans and land absorb and emit carbon dioxide). Though only relatively few global coupled climate models include the complex processes involved with modeling the carbon cycle, this feedback is positive (i.e., adding to more warming) in all models so far considered. Therefore, the addition of carbon cycle feedbacks provides higher values on the warm end of the uncertainty ranges.

Rising global temperatures are very likely to raise sea level by expanding ocean water and melting mountain ice caps and glaciers. Recently observed ice sheet dynamical processes that could produce potentially larger contributions to sea level rise than accounted for in the present estimates are not fully included in existing models of the Greenland and Antarctic ice sheets assessed for the AR4. Therefore larger increases in sea level rise than the present projections cannot be excluded. Consequently, the AR4 cannot quantify a full uncertainty range of sea level rise at the end of the 21st century. Based on the existing models available for assessment, the central values for projections of sea level rise by 2100 are similar to previous estimates, ranging from about 30 to 40 cm. About 60 percent to 70 percent of this increase is due to thermal expansion of sea water (i.e., as water warms, it expands) and is thus connected to the more certain estimates of warming of surface air temperatures. There is less certainty with regards to the other components of sea level rise (contributions from melting land glaciers and small ice caps, the net balance between snow accumulation and melting ice for Greenland and Antarctica, and the dynamic ice flow contributions from Greenland and Antarctica). This is reflected in the ranges of sea level rise that differ from previous estimates, due in part to the way the uncertainty of these contributions is taken into account. This is an area of great concern and active ongoing research given the potential consequences.

The projected globally averaged temperature increase is also reflected by patterns of regional climate changes. As noted in previous assessments, this pattern for temperature change is characterized by greater warming over land compared to oceans, and more warming at the high northern latitudes. Associated with these temperature changes, there are projected decreases of snow cover, and increases in thaw depth over most permafrost regions. Reductions in sea ice go along with the increased temperatures, with a sea-ice free Arctic by the end of the 21st century in the high forcing scenario in some models. The pattern of future precipitation change indicates likely increases at higher latitudes, such as the northern tier of states, and decreases over subtropical land areas such as the Southwest U.S.

It would seem that the relatively small increases in average temperature amounting to a few degrees may not make that much difference. However, such small changes in average values can lead to much larger changes of extreme weather and climate events. For example, it is very likely that heat waves will increase in intensity, frequency and duration, with heavy precipitation events also increasing. These projected changes in extremes continue trends we have already observed.

Though present-day global climate models used for the climate change projections discussed above have inherent limitations in simulating hurricanes, new types of specialized models have been formulated to study such possible future changes. From a range of models, it is likely that future tropical cyclones (typhoons and hurricanes) will become more intense with larger peak wind speeds and more intense precipitation. This is physically consistent with ongoing increases of sea surface temperature since there is a well-established link between warmer water and hurricane intensity. There is less confidence in projections of a global decrease in numbers of hurricanes since the model results are not as consistent.

There has been some interest in the media and in Hollywood regarding the possibility of an abrupt shutdown of the Atlantic Ocean meridional overturning circulation (MOC). This large-scale ocean circulation system, sometimes called the "ocean conveyor belt," transports heat northwards, in part via the Gulf Stream, to the North Atlantic. A warming of the North Atlantic from increasing greenhouse gases could produce more precipitation and warmer water that would stabilize this overturning circulation and consequently reduce the amount of northward heat transport. Using this line of reasoning, if the MOC suddenly shut down, there could be a sudden decrease in northward heat transport and possibly a large cooling of the North Atlantic region. Research assessed in the IPCC AR4 indicates that it is very likely that the MOC will indeed slow down during the 21st century. With the weakening of this circulation, there is somewhat less heat transported northward. But there is still a future net increase of surface air temperatures over the North Atlantic since the warming from the increased greenhouse gases overwhelms any cooling from the MOC slowdown. Additionally, it is very unlikely that the MOC will undergo a large abrupt shut-down during the 21st century, with an associated cooling from such a sudden shut-down also very unlikely. No global coupled climate model simulation assessed in the AR4 produces such an abrupt change, even if Greenland ice melt is taken into account. However, changes in the MOC in the 22nd century and beyond cannot be assessed with confidence at this time.

Summary

The IPCC AR4 represents the current state of human understanding of climate science and climate change. Projected changes of future climate have relied on an unprecedented set of coordinated climate change experiments undertaken by the international climate modeling community, and the U.S. modeling groups have played a prominent role in this process. The projections of future climate are consistent with earlier IPCC assessments in terms of the magnitude of global changes. This is reassuring since successive generations of climate models are now producing comparable results from assessment to assessment. But there are now many more details as well as increased certainty regarding quantifications of regional climate change, extremes, hurricanes, climate change commitment, ocean circulation changes, and better information regarding both near-term and longer-term climate change.

BIOGRAPHY FOR GERALD A. MEEHL

Gerald Meehl received his Bachelor's (1974), Master's (1978), and Ph.D. (1987) degrees in climate dynamics from the University of Colorado in Boulder. Since 1973, he has worked at the National Center for Atmospheric Research (NCAR) in various capacities, including participating in the Tropical Wind Energetics Reference Level Experiment (TWERLE) in Pago Pago, American Samoa, and Christchurch, New Zealand (1975–76), in the Monsoon Experiment (MONEX) in Bintulu, Sarawak, Malaysia, and Kathmandu, Nepal (1978–79), and in the Tropical Ocean Global Atmosphere (TOGA) Coupled Ocean Atmosphere Response Experiment (COARE) in Townsville, Australia, Kapingamarangi, FSM, Pohnpei, FSM, and Republic of Nauru (1992–93). Since 1979, as a scientist in the Climate and Global Dynamics Division, he has studied the interactions between El Niño/Southern Oscillation (ENSO) and the Indian monsoon, analyzed the results from global coupled ocean-atmosphere general circulation models at NCAR, and examined the possible effects of increased carbon dioxide, sulfate aerosols, and other forcings on global climate. He is the author of more than 140 scientific papers in peer-reviewed journals, and has contributed chapters to several textbooks. He was a contributing author for the Intergovernmental Panel on Climate Change (IPCC) 1990 and 1992 assessments, a Lead Author for the chapter on climate model projections of future climate change for the 1995 IPCC assessment, a Coordinating Lead Author for the chapter on climate model projections of future climate change for the IPCC Third Assessment Report published in 2001, and a Coordinating Lead Author for the chapter on global climate change projections for the 2007 IPCC Fourth Assessment Report. Among his current committee appointments, he is a member of National Research Council Climate Research Committee, Co-Chair of the Community Climate System Model Climate Change Working Group, Co-Chair of the World Climate Research Programme CLIVAR Working Group on Coupled Models (WGCM), and Chairman of the WGCM Climate Simulation Panel which has coordinated analyses of global coupled climate model simulations for the IPCC Fourth Assessment Report.

DISCUSSION

THE IPCC PROCESS

Chairman GORDON. Thank you, Dr. Meehl.

Now, Dr. Solomon, the message I am taking away from this Report is that the climate is changing, the Earth is getting warmer, human activities have started and continue to drive this change. Have I gotten that message right?

Dr. SOLOMON. Basically, yes. I would put some "very likely"s in there, but I would agree with you.

Chairman GORDON. Thank you. And Dr. Solomon, I understand that all 113 nations had to agree on that. This had to be a unanimous Report, is that correct?

Dr. SOLOMON. All of the nations present in Paris, including the United States, were in agreement with the final document. That is correct. It was a consensus document.

Chairman GORDON. And by virtue of that, does that mean that this would be on the conservative side of a report?

Dr. SOLOMON. I would actually say that the point of this kind of a report is to say what we know, what we don't know, and what the remaining uncertainties are. I don't think that a report, such as ours, if it is intended to be the sort of global consensus statement that it is could go any farther than we have gone. I think we have done a very fair job in reporting what is known and what is not known. I would not call it conservative, personally.

GLACIER MELT ACCELERATIONS

Chairman GORDON. And Dr. Alley, I understand that the research had to be cut off by the end of 2005, and so additional information that came from Greenland with the ice floats and things of this nature were not a part of this information. Is that correct?

Dr. ALLEY. Some of the information on acceleration in Greenland did come in time to be assessed properly and a couple of recent papers are not included. That is correct.

Chairman GORDON. And from press reports that I have seen, it indicated that in terms of the rise in sea level, you were somewhat limited to the change of temperature. As the water got warmer, obviously, it would expand. How limited were you in the discussions and the new information concerning Greenland and elsewhere where glaciers were melting?

Dr. ALLEY. The melting of mountain glaciers, in the Alps, for example, or in the Rockies, is taken account of, and—with improved accuracy, so I think we understand better. The changes in snowfall and melting on top of Greenland and on top of Antarctica are also taken into account and somewhat better than it had been. The——

Chairman GORDON. But was it taken into account in terms of the rise in the sea level?

Dr. ALLEY. It is taken into account in terms of rise in sea level. What is missing is an accurate assessment of these changes in the spreading, the changes in the flow, how much the self-lubrication of the ice or the loss of the spatulas would contribute to accelerated flow in a warmer world. And we simply don't have the scientific understanding to provide an accurate assessment of that.

Chairman GORDON. But we know it is not going to get slower. It is only going to get faster. The question is just how much faster.

Dr. ALLEY. But we don't even really know that, because that sort of implies a knowledge that we are trying rather desperately to build for you right now. Certainly, we have seen glacier accelerations, and we have seen those accelerations in response to warming. We have fairly high confidence in that. If you see future warming, it, perhaps, would not be surprising that if warming causes mass loss that more warming would cause more mass loss, but we are still fighting on that. This document works very, very hard to be an assessment of what is known scientifically, what is well founded in the refereed literature, and when we come up to that cliff and look over and say we don't have a foundation right now, we have to tell you that. And on this particular issue, the trend of acceleration of this flow with warming, we don't have a good assessed scientific foundation right now.

Chairman GORDON. How long would you expect that that would be before you will?

Dr. ALLEY. I don't know. I am very optimistic that we will be better in five years. I am doubtful that we will have as good an understanding of that as we do of, say, mean global surface temperature that Dr. Meehl was talking about.

Chairman GORDON. Thank you, Dr. Alley.

Mr. Rohrabacher.

Mr. ROHRABACHER. Thank you very much, and thank you very much, Dr. Alley, for your honesty and your candor, considering that people obviously wanted you to say something else than what you have just told us, that they would like to have certainty. For the record, Mr. Chairman, I would like to put in the record a list of a number of scientists and statements by scientists, very well respected statements and very well respected scientists, who are not part of this so-called consensus that any climate change is being caused by human activity. If I could submit those for the record at this point.

Chairman GORDON. Certainly, Mr. Rohrabacher, and I will also point out that the Minority had the opportunity to call any of these witnesses and have them be part of this panel——

Mr. ROHRABACHER. I appreciate that——

Chairman GORDON.—and had quite a bit of time to be able to do that. But certainly this will add to our report. And without any objection, they will be made a part of the record.

[The information follows:]

INFORMATION TO BE PLACED IN THE RECORD RELATING TO THE HOUSE SCIENCE & TECHNOLOGY COMMITTEE HEARING ON THE STATE OF CLIMATE CHANGE SCIENCE 2007 ON FEBRUARY 8, 2007 BY CONGRESSMAN DANA ROHRABACHER

Timothy Ball

"Believe it or not, Global Warming is not due to human contribution of Carbon Dioxide (CO_2). This in fact is the greatest deception in the history of science. We are wasting time, energy and trillions of dollars while creating unnecessary fear and consternation over an issue with no scientific justification."

Monday, February 5, 2007
Open News web site

http://www.opednews.com/articles/opedne_daniel_g_070207_global_warming_3a_the_.htm

Dr. Tim Ball, Chairman of the Natural Resources Stewardship Project *(www.nrsp.com),* is a Victoria-based environmental consultant and former climatology Professor at the University of Winnipeg. He can be reached at: *letters@canadafreepress.com*

Fred Singer

"Crucially, greenhouse models cannot explain the observed patterns of warming—temperature trends at different latitudes and altitudes. These data, published in a U.S. Government scientific report in May 2006, lead us to conclude that the human contribution is not significant. Most of current warming must therefore stem from natural causes. It may well be part of an unstoppable solar-driven 1,500-year cycle of warming and cooling that's been documented in ice cores, ocean sediments, stalagmites, and so forth—going back a million years.

"If indeed most of current warming is natural rather than from greenhouse gases, there is little point in reducing carbon dioxide emissions. Further, carbon dioxide is not an atmospheric pollutant. Programs and policies for carbon dioxide control should therefore be scrapped—including uneconomic alternative energy sources, carbon-sequestration efforts, and costly emission-trading schemes. All of these waste money and squander scarce resources, without in any way affecting the atmosphere or climate. Humans have adapted to major climate changes in the past, and we should have no problem doing so in the future."

The Science and Environmental Policy Project's *The Week That Was* newsletter (2/3/07)

http://www.sepp.org/Archive/weekwas/2007/February%203.htm

S. Fred Singer, an atmospheric physicist, is Professor Emeritus of environmental sciences at the University of Virginia, adjunct scholar at the National Center for Policy Analysis, and former Director of the U.S. Weather Satellite Service. He is also a research fellow at the Independent Institute and author of *Hot Talk, Cold Science: Global Warming's Unfinished Debate* (The Independent Institute, 1997).

Bill Gray

"I think we're coming out of the little ice age, and warming is due to changes to ocean circulation patterns due to salinity variations."

Quote from an article in the *Daily Reporter-Herald* (9/19/06)

Dr. William M. Gray is a world famous hurricane expert and Emeritus Professor of Atmospheric Science, Colorado State University.

From an interview with Dr. William M. Gray in *Discover Magazine,* September 2005, Title: "Weather Seer: 'We're Lucky' "

A few years ago, you almost called it quits because you'd lost so much funding. What made you continue?

G: I don't have the budget that I had, so I have to cut back my project way back. I am in retirement. I'm still working everyday, but I don't teach and don't have as many graduate students and as much financial need. I've got a little money from Lexington Insurance out of Boston, and I have some National Science Foundation money. For years haven't had any NOAA, NASA, or Navy money. But I'm having more fun. Right now I'm trying to work on this human-induced global warming thing that I think is grossly exaggerated.

You don't believe global warming is causing climate change?

G: No. If it is, it is causing such a small part that is negligible. I'm not disputing that there has been global warming. There was a lot of global warming in the 1930's and '40s, and then there was a slight global cooling from the middle '40s to the early '70s. And there has been warming since the middle '70s, especially in the last 10 years. But this is natural, due to ocean circulation changes and other factors. It is not human induced.

That must be a controversial position among hurricane researchers.

G: Nearly all of my colleagues who have been around 40 or 50 years are skeptical as hell about this whole global warming thing. But no one asks us. If you don't know anything about how the atmosphere functions, you will of course say, "Look, greenhouse gases are going up, the globe is warming, they must be related." Well, just because there are two associations, changing with the same sign, doesn't mean that one is causing the other.

With last year's hurricane season so active, and this year's looking like it will be, won't people say it's evidence of global warming?

G: The Atlantic has had more of these storms in the least 10 years or so, but in other ocean basins, activity is slightly down. Why would that be so if this is climate change? The Atlantic is a special basin? The number of major storms in the Atlantic also went way down from the middle 1960s to the middle '90s, when greenhouse gases were going up.

Why is there scientific support for the idea?

G: So many people have a vested interest in this global warming thing. . .all these big labs and research and stuff. The idea is to frighten the public, to get money to study it more. Now that the cold war is over, we have to generate a common enemy to support science, and what better common enemy for the glove than greenhouse gases?

Are your funding problems due in part to your views?

G: I can't be sure, but I think that's a lot of the reason. I have been around 50 years, so my views on this are well known. I had NOAA money for 30 some years, and then when the Clinton Administration came in and Gore started directing some of the environmental stuff, I was cut off. I couldn't get any NOAA money. They turned down 13 straight proposals from me.

GLOBAL WARMING TRENDS

Mr. ROHRABACHER. Thank you.

My question—well, first of all, Dr. Solomon, is a glacier named after you?

Dr. SOLOMON. Yeah, I am afraid so.

Mr. ROHRABACHER. Is it melting? I am serious about that. Is the glacier named after you melting?

Dr. SOLOMON. Well, that particular one is at 78 degrees south, sir. It is at such a high latitude in the Antarctic that——

Mr. ROHRABACHER. So it is not melting?

Dr. SOLOMON.—it is out of reach of global warming.

Mr. ROHRABACHER. It is out—it is not melting. Thank you very much.

Let me—I am not a scientist. Look, I am a former journalist and a writer, and so I have to really, you know, look down and see what is being said, condense things into the real meaning. Let me ask you just a couple fundamental questions.

I saw on the History Channel a whole big special on the mini ice age. Was there a mini ice age, and did it end at about the middle of the 19th century? Or you know, were there really Vikings that were living at a much higher temperature on Greenland 1,000 years ago, or are we being—is the History Channel just telling us, you know, a myth?

Dr. TRENBERTH. Mr. Rohrabacher, if I can have a crack at that. There was a period called the little ice age——

Mr. ROHRABACHER. Okay.

Dr. TRENBERTH.—that, indeed, occurred around about that time up until about the end of, say, the 19th century, which was——

Mr. ROHRABACHER. All right.

Dr. TRENBERTH.—clearly cooler. It is a little bit of a Eurocentric view of the world, though, because a lot of it was certainly focused in the North Atlantic European region where, you know——

Mr. ROHRABACHER. Well, that, of course, is where we had all of the statistics being kept, and so at that time period, of course it would be Eurocentric, because they didn't keep all of those temperature records in other places in the world. So there was a mini ice age, and it went down to about the middle of the 19th century. I couldn't help but notice that the chart that was presented started the low point of this mini ice age. It started there to prove that there was a global warming trend.

Now if you start at the bottom of something that is recognized as a time of cooling on the Earth, isn't it going to go up naturally if there is a natural cycle going on?

Dr. TRENBERTH. The instrumental record, we have been able to push it back to 1850, and that is the reason it starts then. And the way we would characterize it is that there is really not much change up until about 1920. There is a warming that goes on from about 1920 to 1940, and we believe that some of that—the work that the models have done and the instruments and what has happened with the sun is that a part of that is natural and associated with changes in the sun. It is really only in the last 35 years, since about 1970, that the global warming aspect has clearly emerged above these levels of natural variability. So——

Mr. ROHRABACHER. And we are only talking about one degree, a one degree change, right? And in fact, over these last 20 years, you are talking about it is less than one degree, because your one degree started back in the middle of the 19th century.

Dr. TRENBERTH. Well, one degree Celsius. Over one degree Fahrenheit since 1970.

Mr. ROHRABACHER. Okay. One degree since 1970. Now is it possible that there is a natural cycle going on here? Is that a possibility?

Dr. TRENBERTH. This is one of the things that we can do now. Natural cycles also have causes. They—you know, they come from somewhere.

Mr. ROHRABACHER. Like sunspots.

Dr. TRENBERTH. Sunspots or——

Mr. ROHRABACHER. Okay.

Dr. TRENBERTH.—changes in the heat of the ocean or——

Mr. ROHRABACHER. I have only got a little bit of time left. Let me ask you—I am sorry, because you know, we are only given a very short period of time to ask. What percentage of what are called greenhouse gases are created by nature or—and that is even leaving the sunspot issue out, as compared to humankind? All of humankind produces what, 10 percent of the greenhouse gases, five percent?

Dr. SOLOMON. Well, this is in my area of research, Mr. Rohrabacher, so I would like to respond. On the issue of solar activity, we have direct measurements in how the sun has varied since 1970. They show very clearly that the solar, in radians, changes since 1970 have been very small, much less than the changes in the energy budget due to greenhouse gases. You will find that figure to——

Mr. ROHRABACHER. Okay. So the greenhouse gases are what percentage again?

Dr. SOLOMON. Well, greenhouse gas contribution to warming far outstrips the solar brightness changes. That is a figure——

Mr. ROHRABACHER. Okay. But what percentage of greenhouse——

Dr. SOLOMON. May I continue——

Mr. ROHRABACHER. No, no, because I have only got a little bit of time. I am sorry——

Dr. SOLOMON.—because you have asked——

Mr. ROHRABACHER.—I control this time. You don't. I am asking what percentage of the greenhouse gases are created by human beings?

Dr. SOLOMON. Yeah. That is what I was just about to get to——

Mr. ROHRABACHER. Okay.

Dr. SOLOMON.—actually. Thank you. If you look at Figure 1 of our Summary for Policy-makers, it actually shows you the time series of carbon dioxide, for example, and you will see it has increased markedly since 1750——

Mr. ROHRABACHER. I am not asking about that.

Dr. SOLOMON. It is almost entirely due to human activities.

Mr. ROHRABACHER. Listen. Listen. Hold on. Excuse me. But unless you are going to be honest about this, we are not going to have an honest discussion. At least Mr. Alley was being honest about it, saying we don't know. If I ask you a direct question, what percentage of the greenhouse gases are caused naturally rather than by human beings, can't anybody answer that directly?

Dr. SOLOMON. The CO_2 increase is caused almost entirely——

Mr. ROHRABACHER. I didn't ask that.

Dr. SOLOMON.—by human beings.

Mr. ROHRABACHER. I didn't—listen. I am asking you a direct question, what percentage of the greenhouse gases are made by human beings and what percentage are made by nature?

Dr. SOLOMON. I would say a fair number regarding the increase since 1750 is that greater than 90 percent of the increase has been caused by human activities.

Mr. ROHRABACHER. That wasn't the question, was it? Why can't you—listen, this is very dishonest. You are supposed to be a scientist. I have asked you a direct question. Can anybody else in the panel be honest about the answer?

Dr. SOLOMON. Sir, I am really trying to be honest.

Mr. ROHRABACHER. What percentage of the greenhouse gases in our atmosphere and created in our atmosphere are being created by nature versus humankind? I have asked you that four times now and have been dodged four times.

Dr. SOLOMON. No, sir, I am not dodging your question. I am sorry.

Mr. ROHRABACHER. Does someone else—I didn't say the increase.

Dr. SOLOMON. There is a baseline.

Mr. ROHRABACHER. I didn't say increase.

Dr. SOLOMON. There is, indeed, a baseline.

Mr. ROHRABACHER. What is the baseline?

Dr. SOLOMON. The baseline for carbon dioxide is 270 parts per million. What we are now at is about 380 parts per million.

Mr. ROHRABACHER. Excuse me, I am asking—Mr. Chairman——

Dr. SOLOMON. That increase is due to human activity.

Mr. ROHRABACHER. Mr. Chairman, I don't—I would like my time not to be spent by witnesses not——

Dr. SOLOMON. 270 out of 380. I can——

Chairman GORDON. Well, your time has been up for quite some time.

Mr. ROHRABACHER. Well, I wish we could have this—is everyone else afraid to answer that question as well?

Mr. BAIRD. Would the gentleman from California yield for one second?

Mr. ROHRABACHER. Sure.

Mr. BAIRD. My belief is that the answer resides in what the gentlelady just said in the following sense. If you take a baseline, one might presume that the baseline is the natural prevalence of CO_2, because——

Mr. ROHRABACHER. That is not my question.

Mr. BAIRD. No, I understand that, but I am going to get to your question——

Mr. ROHRABACHER. I have been trying to get an honest——

Mr. BAIRD. Stay with me. I am going to get to your—I am going to get to it.

Mr. ROHRABACHER. All right.

Mr. BAIRD. And then if you look at where we are now——

Mr. ROHRABACHER. Yes.

Mr. BAIRD.—that difference between baseline and where we are now would presumably yield the information you are asking for, which is what percentage of the carbon is caused by——

Mr. ROHRABACHER. No, no, no. That is not the suggestion at all—I mean, that is not the way. I mean, it is a simple question, and every scientist that I have asked has said it is less than 10 percent of any of the greenhouse gases are caused by human activity. And I was just trying to find out whether these scientists agreed with the assessment that I have heard from all of the other scientists——

Chairman GORDON. The gentleman's time has expired, but let me suggest that if you will put those questions in writing——

Mr. ROHRABACHER. Okay.

Chairman GORDON.—that the panel will have an opportunity to give you the best answer that they can.

Mr. Baird.

MORE ON THE IPCC PROCESS

Mr. BAIRD. I thank the gentleman.

I thank the expert testimony.

Is it correct that there were 450 Lead Authors, 800 contributing authors and over 2,500 reviewing authors who participated in this study or this Report? Is that an accurate——

Dr. SOLOMON. That is the number across all three Working Groups, sir. For Working Group I, the numbers are in my testimony, 152 Lead Authors, 400 contributing authors, 600 expert reviewers.

Mr. BAIRD. Was there a——

Dr. SOLOMON. The numbers that you quoted are for group I, II, and III that you were——

Mr. BAIRD. Okay.

Dr. SOLOMON.—talking about. We are Group I only.

Mr. BAIRD. Thank you. Was there an effort to intentionally exclude people who might have a different opinion about global warming, or were people allowed to participate and offer comments if they disagreed with global warming hypotheses?

Dr. SOLOMON. The review process was entirely open. Scientists could register on the web. They only had to say who they were. They weren't asked anything else, and they were sent whatever materials they wanted to review. So it was totally open to anyone who wished to review it.

Mr. BAIRD. So presumably, if they had had compelling arguments and data to persuade their colleagues to reach contrary conclusions, they had ample opportunity to do that?

Dr. SOLOMON. They had ample opportunity to express their views, indeed.

Mr. BAIRD. Dr. Trenberth, you seem to want to comment.

Dr. TRENBERTH. In my chapter, yes, there were many well-known, so-called skeptics that participated as reviewers, and their comments were all addressed.

Mr. BAIRD. So it would not be accurate to suggest that this was somehow a biased report, and one could actually see if there were—some of my colleagues are raising questions that they have heard from so-called skeptics, one could see those answers to the skeptics in the Report or presumably in the web dialogue that led to the Report?

Dr. TRENBERTH. The Report is changed, of course, in response to comments, but there are many comments. And in addition, all of the comments are responded to in writing, and there is a file, there is a great big file at the technical support unit, which has the responses to every comment and how they were addressed.

MORE ON GLOBAL WARMING TRENDS

Mr. BAIRD. I appreciate that.

So what you are saying is there is a baseline level of CO_2 produced by agricultural processes, sea changes, et cetera, the normal kind of fluctuations? But beyond that baseline, we have seen a substantial increase in CO_2 that correlates quite closely to the production of CO_2 by human-related activity, i.e., predominantly the consumption of fossil fuels. Would that be a fair statement?

Dr. SOLOMON. Indeed. Figure 1 of the Summary for Policy-makers shows a constant CO_2 for 9.9 thousand years, approximately, followed by a dramatic increase in the last century, which is essentially entirely attributable to human activities.

Mr. BAIRD. So to sum—while it is an intriguing question to ask, what percentage of the total CO_2 budget is produced by human activity in terms of gauging changes in the CO_2 budget, which may correlate to changes in temperature. It may, in fact, be the change that is of most significance and importance for understanding here, not just the base level—the differential percentages, because prior to that, presumably, the CO_2 production of humankind was background, a rounding error, possibly.

Dr. SOLOMON. I am afraid I don't know the number exactly, but again, in terms of concentrations, 270 parts per million by volume in, say 1700, 270 parts per million 1,000 years before that, today, 380 parts per million, sir, so——

Mr. BAIRD. So could we not assume that is 110 parts per million?

Dr. SOLOMON. 110-part-per-million increase due essentially entirely to human activity. That is what I am trying to say.

Mr. BAIRD. So 110 parts per million is what——

Dr. SOLOMON. Out of 270.

Mr. BAIRD. Correct. So that is about, what——

Dr. SOLOMON. A third.

Mr. BAIRD.—30 percent. So that may answer the gentleman from California's question, I think, and that is what I was trying to get to earlier.

But more importantly, in terms of the global warming debate, if you have got that increase presumably in, I think—we cannot dispute that we produce more CO_2. I mean, that would be pretty hard to dispute on any credible scientific grounds. We also seem to have pretty clear evidence from this Report of the increase in temperature. While correlation is not causation, correlation can give us some pretty good insights.

One final question. Skeptics may ask you to prove beyond a shadow of a doubt that this global warming, which we are observing, is caused by human consumption—production of CO_2. I don't think that is scientifically possible. I used to teach scientific method. I hold a doctorate in the scientific field. You can't do it. But that doesn't mean one does not act on the best available scientific information. Will you care to comment on that?

Dr. MEEHL. Yeah, maybe I can comment on that.

The real big advance we have seen in the last five years with trying to address this question of attribution, that is basically your question, you know, how can we attribute, how can we be sure that humans are causing this warming, are these computer climate models we use, and they have been improved quite a bit. We have been putting in single factors that we think affected climate over the 20th century, natural and human-produced. So we can put in solar variability by itself in the model, run it for the 20th century, see how the climate system responds. We can put volcanic activity in. We get a big volcano going off that cools off the climate for a couple of years and see how that responds. We can put in other forms of air pollution, sulfate aerosols, which are small particles that reflect sunlight, so that is a cooling effect. We can put that in separately and see how it affects the climate. We can put in increases of greenhouse gases produced by human activity and see how that affects the climate. So we can deconstruct the 20th century climate in a way that we just couldn't do taking observations, because the observations you are seeing out the window are a combination of all of these factors wrapped up together. There is a great use of these models as tools, so we can actually look at each of these things separately and in combination to see how they contributed to what we observed over the 20th century. And as was alluded to earlier, the results from these studies, the first started to be done about five years ago, and we have many more now that we assessed, show that most of the warming that we observed in the first part of the 20th century was natural. Not many volcanoes were going off. We had an increase of solar output. Then we had the level period from the 1940s to the 1970s when the big increase in industrial activity after World War II produced a lot more air pollution. That was a cooling effect, but the increase in greenhouse gases were still going up. That was warming, but they about balanced until about the mid-1970s. Then the ongoing increases of greenhouse gases plus some efforts by industrialized countries to reduce visible air pollution then produced the big warming we have seen since the 1970s.

So I think by being able to do these kinds of studies with these calibrated models, we can make this statement that it is very likely that most of the warming we have seen in the last half-century or so is due to human activities. That is where that comes from.

Mr. BAIRD. I appreciate that and yield back.

Chairman GORDON. Thank you, Dr. Meehl.

Mr. Sensenbrenner is recognized for five minutes.

Mr. SENSENBRENNER. Yes. Thank you very much.

I would like to ask members of the panel to rank the three big greenhouse gases, CO_2, methane, and NO_X as to which is the biggest culprit, which is the second biggest, and which is the third biggest.

Dr. SOLOMON. Figure 2 of the summary shows that explicitly, so what you can see there is that carbon dioxide is the largest contributor. Methane is the second. Nitrous oxide is also significant, and that is shown in the middle of the second column. And the halocarbons also contribute. Tropospheric ozone does as well.

Mr. SENSENBRENNER. Okay. Now——

Dr. SOLOMON. You can see the ranking, sir.

Mr. SENSENBRENNER.—by looking at your Figure 1, Dr. Solomon, CO_2 has gone up about 40 percent since 1750 whereas methane has gone up, by my rough figures, about 130 percent. What is causing the difference between the increase of human activity is the culprit on all of that?

Dr. SOLOMON. The sources are different. In the case of methane, the primary sources are agricultural, whereas in the case of carbon dioxide, the primary sources are fossil fuel, so they are coming from different things.

Mr. SENSENBRENNER. Does that mean that to stop this huge growth of methane, we better put catalytic converters on the back of cows?

Dr. SOLOMON. Certainly, animals are one contributor to the increases in methane. You are quite right. There are——

Mr. SENSENBRENNER. Now you are hitting the Wisconsin economy right between the horns.

Dr. SOLOMON. I can always tell you I love your cheese, sir. I don't know what else to say.

Mr. SENSENBRENNER. Well, we better make sure that there are cows there to produce it, and we appreciate your patronage.

Dr. Trenberth.

Dr. TRENBERTH. Yes. I am from New Zealand, and it turns out New Zealand is pretty unique in that it emits more methane than carbon dioxide because of all of the sheep and cows in New Zealand, and there is a tremendous amount of research going on on exactly that topic and how to change feed in order to reduce methane coming out of the mouths and the other end of animals.

GREENHOUSE GAS PRODUCTION: COUNTRY COMPARISONS

Mr. SENSENBRENNER. Okay. Have you done any figures or any calculations as to which particular countries are culprits in emitting more or less CO_2 and methane relatively? Meaning, do you see more methane in Europe and more CO_2 in North America, or don't you know?

Dr. TRENBERTH. There are charts on those. I don't have those numbers at my fingertips. And the other revealing factor, which you may want to look into, is the amount per capita, and I do know that the United States leads the world in both categories. And that per capita, the United States emits about two and a half times more carbon dioxide than in Europe, for instance, and about 10 times more than China and about 20 times more than India, but of course, the per capita aspect and the number of people then makes a very big difference, and so that is another important——

Mr. SENSENBRENNER. Well, now, you know, I was the head of the Congressional Observer Delegation to Kyoto, so I went and watched all of that stuff. One of the meetings that my bipartisan delegation had was with the Chinese delegation. And they told Mr. Dingell that they weren't going to cut down on their greenhouse gas emissions, no way, no how. Mr. Dingell kept on going forward for 20 years, seeing if they would change their mind, and if I didn't tell him to stop, he would still be there, and we would probably be up to the year about 15,000. The Chinese Government, last week, when your report was coming out, reiterated the fact that it was going to stonewall dealing with this issue because it needed to burn more hydrocarbons in order to develop its economy. If you have the world's biggest country and the world's most rapidly developing economy not participating in this and the United States, for example, doing what has been suggested here, have you thought about the economic impact on where jobs go, meaning to China and away from the United States?

Dr. TRENBERTH. It is not for me to really say that, but I would emphasize, indeed, that this is a global problem, and so whereas other countries are concerned about the United States' emissions, indeed, I think we need to be concerned about other countries' emissions and therefore the international negotiations are an important part of this problem.

Mr. SENSENBRENNER. But with all due——

Chairman GORDON. The gentleman's time has expired.

Mr. Udall.

CLIMATE RESEARCH

Mr. UDALL. Thank you, Mr. Chairman.

I would note for my colleague from Wisconsin that Dr. Bartlett, who has just recently traveled to China, had some very interesting discussions with the Chinese, and I am going to maintain my own time, but I am hoping to cue Dr. Bartlett, and perhaps when he has some questions, to talk about what the Chinese are doing. So their actions are speaking, certainly, as loud as their words. They understand that the present path cannot be maintained in any sustainable fashion.

Dr. Trenberth, I want to turn to your testimony. You restate the Report's findings that we're already committed to a significant level of climate change in that you believe we need to mitigate the effects of the coming changes. And I might like to, in that spirit, note that yesterday I introduced H.R. 906, the *Global Change Research and Data Management Act of 2007,* along with my good friend and colleague from South Carolina, Mr. Inglis. And this bill updates the existing law that formally established the U.S. Global Change Research Program in 1990, and it would help reorient the research program to be more user-driven, which would help local and state and regional and national policy-makers make more informed decisions.

Would you speak to that from your point of view? Do you believe that improving these regional models would enable us to produce these vulnerability assessments that you reference in your document?

Dr. TRENBERTH. One of the things that we struggled with in our chapter in dealing with observations is that in a number of countries, in fact, observations, especially the surface observations, are decaying over time. And as a recent National Academy of Sciences report has stated, there are real risks in losing a lot of space-based observations in the future. Space-based observations are very difficult to deal with, as well, because every time you put a new satellite up with a new instrument, it is very hard to know exactly how those measurements relate to the previous set of measurements. And so it depends on whether these satellites have been launched for climate purposes and whether the observations are adequately calibrated or whether they are launched for other purposes, such as weather, where those issues are not so great. And what the science community is certainly urging is that we pay more attention to these kinds of issues and the degradation that is going on in the observing system, because this builds the information base as to what is going on and also why. So in this case, we are not just talking about observations of temperature and precipitation, and so on, but also the observations on why the climate is changing, what is happening to the composition of the atmosphere, what is happening to the sun, and so on, and I think there is a very compelling case that we need to do more in this area to track why this winter in the East Coast was so warm up until recently, why there has been no snow and it has been very warm in Europe, and they are having trouble with the World Cup Skiing, what the role of El Niño is in this, which is playing a role, understanding the variability and the climate change aspects and tracking what is going on. This relates to natural variability as well. If it is natural variability playing a role, we should be able to measure it and account for it. So if the ocean currents are changing, the Gulf Stream is changing, we should be able to measure that and assess its impact and whether or not there is going to be a shut down in the Gulf Stream and so on. So I think a compelling part of what we need to do, also, is to build an information base and a climate service that addresses these kinds of concerns.

Mr. UDALL. Doctor, is it fair to say what you are proposing and suggesting we could do is gathering and assessing and concluding about the data, it is—you are not involved in the processing, okay, what do we do about carbon emissions? And the reason I am asking you that is to promote the idea behind this legislation I proposed, which is to make better use of our resources, be more efficient in this whole area of research, and then we can continue to have the debate that we are having here and all over the world.

Dr. TRENBERTH. Yeah, the mitigation aspects are dealt with in Working Group III, and I would urge you to wait for their report in May of this year. It is not an area where I am an expert. All I can say is, for myself, I have put solar panels on the roof of my house.

Mr. UDALL. Thank you.

Dr. Solomon, somebody suggested that—particularly on the heels of Mr. Sensenbrenner's comments about methane, that humans are actually temporary carbon sinks and that we could think about ourselves in that regard, but I have never seen a study on the balance between humans as carbon sinks and the methane that we may or may not emit. Be that as it may, what surprised you of the IPCC process?

Dr. SOLOMON. That is an interesting question. I knew pretty well what to expect, having been involved in it for a very long time. I think what surprised me the most was actually how much progress we have, in fact, made from remarkable new databases, from satellites on issues, such as the effects of aerosols, as Kevin was saying, the improvements in observations. Indeed, there is more to be done there, but we just have so much better information now. The advances in modeling, I was very impressed, actually, by the degree of progress we were able to make in this assessment compared to the past one. It surprised me.

Chairman GORDON. Thank you, Mr. Udall. Your time is expired.

Mr. Calvert, you are recognized for five minutes.

CARBON SEQUESTRATION

Mr. CALVERT. Thank you, Mr. Chairman.

I am going to go at this in a different direction. I think that there is pretty much unanimity that there is climate change taking place, global warming taking place, and this committee is gathering information, scientific information within our jurisdiction. And I assume that information will be shared with other committees that will have the jurisdiction to regulate certain industries, such as the coal industry, the automobile industry, the hydrocarbon-fired energy sources within the United States. And so it is important that we try to get it right, because the unintended consequences of taking bad information and trying to make policy is going to have dramatic effects on the economy of this country and certainly for the rest of the world. And so when Mr. Rohrabacher, for instance, is asking the question how much of a percentage, for us laymen, is greenhouse gases relative to natural sources, that is an important question, because—and also, the question of what countries and what regions have an increase relative to natural sources for—we have a better understanding of how we go about that problem. But it has been said that the United States produces 25 percent—or uses 25 percent of the energy in the world, and it is about four percent of the world's population. So you know, you could say that the United States, overwhelmingly, has the most responsibility to regulate its economy in order to meet its responsibilities, especially under the Kyoto accord, which I went to with Mr. Sensenbrenner a number of years ago. So we have got to get it right, because I would suspect the four of you all agree that with the summary of the report, 90 percent confidence that human activity is the cause of global warming. Would you say that all four of you agree to that basic concept, since you are here, obviously, testifying for the majority? And so if, in fact, that is correct, how do we go about tackling this problem? And I think that that is really what this Congress is going to be trying to answer, whether we go into mandatory caps, which was mentioned by the Speaker, or, as I believe, incentives in the economy to bring on new industries that I think will have the same result in the long-term and in the short-term of having—the result of having less greenhouse gases. In that, China—the issue of China has been brought up. I believe China, right now, is opening a new coal-powered plant once a week. And is that approximately correct?

Dr. TRENBERTH. It is less than every three days.

Mr. CALVERT. Less than every three days. The United States—the largest energy source within the United States is still coal, based on our base load power. And I know we are trying to get the clean coal technology. Doctor, do you think that that is possible, that we can sequester the CO_2 that is put out by the coal industry? Do you think that is a possibility and continue to use coal?

Dr. TRENBERTH. This is not an area where I am an expert. It is certainly an area where that potential is, I believe, growing. And there is, of course, some cost to that, but it needs to be balanced against the cost of not doing it as well. But——

Mr. CALVERT. Well, right now, the renewable energy sources in the United States are approximately less than five percent. Ninety-five percent of all energy source in the United States is hydrocarbon-based or nuclear-power-based. Twenty percent of the base load in the United States is nuclear. The rest of it is either coal or gas-powered plants. And so in order for us to really meet the goals that are outlined within the scientific information that is being represented to us, without coal or nuclear power, is that possible? I mean, can we have a sustainable economy without coal or nuclear power?

Dr. SOLOMON. You know, I would just like to emphasize, sir, that this group are physical scientists. That is all we are. We are not economists and——

Mr. CALVERT. No, and I understand that. And you are providing the information that we, as policy-makers ultimately have to make a determination. Because you know, the automobile industry, the coal industry, the manufacturing industry in this country are really depending upon getting it right, getting the right science to us. You know, something was talked about El Niño earlier this year. We were supposed to have an El Niño effect in southern California this year. Unfortunately, it didn't happen, and we are having one of the largest droughts we have ever had. So sometimes, we just don't get it right. And so hopefully we get it right when we make these types of policy decisions.

With that, I yield back the balance of my time.

Chairman GORDON. The gentleman's time is expired.

Ms. Hooley is recognized for five minutes.

ADVANCEMENTS IN CLIMATE RESEARCH

Ms. HOOLEY. Thank you, Mr. Chair. I want to thank all of the panelists for being here today.

Dr. Solomon, I have a question. There seems to be a big change in the certainty assigned to this Report compared to the 2001. Was that because of modeling or was that because of data collection and observation? And was there——

Dr. SOLOMON. Certainly in both areas. We have really seen advances with, by far, more models, models with better physics in them, models with improved representation of processes, such as sea ice and the carbon cycle. We made advances in those areas. In terms of observations, there have also been many, many advances in observations. A lot of satellite information has become available that we just didn't have before. We now have satellite measurements of sea level rise, for example, for the last 10 years. We also have satellite data that allows us to say things about the ice sheets, as Dr. Alley was talking about. And you know, we have also had more warm years, as I tried to emphasize in the testimony. And Dr. Trenberth also has emphasized. So the fact that 11 out of 12 of the last years have been among the warmest is a remarkable and very interesting bit of information.

COOLING IN ANTARCTICA

Ms. HOOLEY. Thank you.

Dr. Trenberth, you say the planet is "running a fever." Are there any areas that can get colder instead of warmer as a result of climate change?

Dr. TRENBERTH. In the interior part of Antarctica, it seems as though it may have even cooled slightly, and we believe that that is a unique part of the globe because of the ozone hole that occurs over Antarctica. And so it has created some changes in the atmospheric circulation there that has led to quite warm conditions in the Antarctic peninsula and the southern part of South America, the decay of the ice shelf occurred in that region, but at the same time, perhaps even slightly cooler conditions on the interior part of Antarctica. So that is one unique area.

IMPACT ON THE WESTERN UNITED STATES

Ms. HOOLEY. Okay. And Dr. Alley, in your testimony, you described the effect of loss of snow pack and—that it will have on the wintertime water supplies in the west. And since I am from the West, can you elaborate the impact on our Western states?

Dr. ALLEY. I really can't, because I am a physical scientist as opposed to an impacts person. What we do observe is that there has been a shift to earlier snowmelt, and what one sees in projections of the future is if that continues so that you lose more and more of your snow pack. And you well know, as a Representative of a Western state, that the snow pack has been important in maintaining stream flow. Now in terms of what that means for the salmon versus the farm or versus the irrigation versus drinking water versus recreation, that is clearly for someone who is wiser than me.

But I think you are well aware, and you are probably wiser than me on these issues.

Ms. HOOLEY. I don't know about that.

THERMAL EXPANSION OF SEAWATER

Dr. Meehl, would you talk a little bit about the thermal expansion of seawater and the effect it has on global sea levels?

Dr. MEEHL. Yes, water has this interesting property that as it warms up, it expands. And so as the warming that is taking place in the climate system penetrates into the ocean, you get ever-increasing layers of ocean water expanding. And as this warming works its way down into the ocean into a deeper and deeper layer, you get more and more thermal expansion. So when we talk about the commitment of climate change, committed warming, it is on the order of centuries. In other words, we have already committed ourselves to centuries more sea level rise from what we have already put into the system just because it is going to take centuries for that warming to work its way all of the way down through the depth of the ocean. And as long as you still have warming that is working its way down, you are going to have an ever-increasing volume of ocean warming up and expanding. So I think that is an important and probably one of the best things we can quantify in terms of sea level rise is thermal expansion. These other aspects related to ice sheets and things like that we have less confidence in.

MITIGATING CLIMATE CHANGE

Ms. HOOLEY. How much time do we have to turn back the clock or do something about it?

Dr. MEEHL. Again, that is kind of a mitigation question, and that is, frankly, out of my area of expertise, but I think just what we can say from the scenarios we have looked at for the 21st century where we see that what we do makes a difference. If we go on a low-emission track, we get less warming. If we go on a high-emission track, we get more warming. And the longer we wait to do something, the worse the problem gets, the harder it is to try to do something about it. So I think those kind of very general conclusions you can draw from the projections chapter in the AR4. In terms of details on exactly how to mitigate the problem, this combination mitigation and adaptation, that is out of our area of our expertise.

Ms. HOOLEY. I would like to ask the other panelists if you can, what do you think about how much time we have to turn this around or change things or try to lower those emissions significantly?

Dr. TRENBERTH. Let me comment. As is clear from the observations, there are already changes underway. I mean, they are already with us, and some of those changes are really, perhaps, already having devastating effects. We mentioned drought, and drought has become widespread in the subtropics in particular, and parts of Africa have suffered greatly from that and our understanding is building now that a component of this is very likely associated with the global warming that is going on. So from the standpoint of Africa, maybe it is already too late.

Chairman GORDON. The gentlelady's time has expired.

Ms. HOOLEY. Thank you.

Chairman GORDON. Dr. Bartlett is recognized for five minutes.

OCEAN CIRCULATION CHANGES

Mr. BARTLETT. Thank you very much.

Mr. Udall mentioned my recent trip to China. I was very surprised and pleased when they began their discussion of energy and talking about post-oil. They get it. Somehow, we don't in this country. I would suggest that there ought to be enormous common cause between those of us who are concerned that there will not be a limitless supply of oil in the world and those of us, and I am in both categories, who are concerned that we are involved in global warming. And I would think that we can harness our joint energies and get more attention to this.

My colleague, Mr. Rohrabacher, is somehow concerned, I believe, that because humans produce only about 10 percent of the greenhouse gases that what we do, maybe, doesn't matter much. And I have a little illustration that may help us to understand that the total amount of gases up there may be somewhat irrelevant relative to what we can do to change that. If you have a seesaw with 100 pounds on each end and you put another 100 pounds on one end, that is really going down, isn't it? If you put 1,000 pounds on each end as the seesaw and you put another 100 pounds on one end, it is still going down, isn't it? So the total amount of greenhouse gases that are up there may be somewhat irrelevant as to our contribution. Obviously, where our Earth's temperature is, it is a balance between the heat we gain from the sun and the heat we lose. And you know, a very small change can produce enormous effects. I was stunned the other day when I read, and I would ask you if this is true, that in the last ice age the world was five degrees centigrade, that is nine degrees Fahrenheit, cooler than it is today. That is correct? And for those that think, gee, a degree or two, my living room goes up and down three or four degrees. That doesn't matter much. Three or four degrees in the world may not matter much. But nine degrees cooler Fahrenheit, and we were in an ice age. With ice sheets coming down to southeast Ohio, you can see the terminal there from those, someone was asking about where it is warmer and where it is cooler. There is an ironic thing that could happen as the result of global warming, that is that the British Isles and northern Europe could become very much colder because we have a big conveyor belt called the Gulf Stream, which carries heat from the tropics up there. And obviously, water is not piling up up there, so it has to come back. And it comes back, because it gets more dense and it drops down. And one of the things that is happening up there may prohibit this increase in density and that is the melting of ice up there, which produces fresh water, which is very much lighter than the salty water. And so if we have a little bit more global warming, we could shut down the Gulf Stream. And if you look at where England is on the globe, it is up about central Canada. I had to stop for refueling in the Emerald Isle. And that really is incredibly green and warm there in Ireland compared to what it would be if it weren't for the Gulf Stream. So we can have enormous changes in climate in certain parts of the world from relatively small changes in temperature.

I was in Antarctica. I have been to the South Pole twice, and of course 90 percent of the world's ice is found there and 70 percent of the world's fresh water is found there in Antarctica. We have a circumpolar stream there, a current, that kind of keeps the warm waters from the north, well, it is north down there, from coming in. Are there any hints that the global warming may interfere with that circumpolar current down there? And if that is true and warmer northern waters could come down, is it possible that we could see very much accelerated changes in temperatures down there? And by the way, if that ice pack melted with all of the others, the ocean levels would rise about 200 feet is my understanding. But 60 percent of the world's population lives within 200 feet of sea level. Is there a potential that global warming could somewhat interfere with that circumpolar current down there, which is keeping the warm waters out and keeping Antarctica the refrigerator it is?

Dr. MEEHL. Maybe I could try taking a crack at this. All of these ocean circulation changes you mentioned, and you have a real good knowledge of it, obviously, are things that we are really concerned about, obviously, as scientists. And one of the things that is really getting a lot of attention, due to a certain Hollywood movie that we all really like, was this sudden shutdown of this overturning circulation in the Atlantic that you mentioned that the Gulf Stream is a part of. And if it suddenly shut down, the idea was that you would suddenly get a lot more colder in the North Atlantic, because you wouldn't be carrying all of that heat up into the North Atlantic that the conveyor belt transfers. So we have looked at that in all of the models that we have run so far. No model that we have run yet, for the 21st century, for the present century, shows a sudden shutdown of this overturning circulation, this conveyor belt. They all show a slowing down of the conveyor belt for the reasons—exactly the reasons you mentioned. It gets warmer and less dense in the high-latitude North Atlantic, therefore you don't get as much sinking, and you just kind of slow down this conveyor belt circulation. But, of course, then that would contribute to less heat transport to the North Atlantic. You think, well, maybe that would give a cooling. When it turns out, to get that slow down, you have to have so much of an increase of greenhouse gases in the atmosphere that the warming itself from those greenhouse gases just swamps, it overwhelms any small decrease of northward heat transport you get from the slowdown of this overturning circulation. So we say, in fact, it is very likely that the overturning would slow down. It is very unlikely that it would suddenly seize up and stop, at least in the 21st century. And that is even taking into account possible contributions from melt water from Greenland and other things that would add to this decrease in density.

Chairman GORDON. The gentleman's time has expired—oh, I am sorry.

Dr. MEEHL. I was just going to say, beyond 2100, we are not as sure, because there may be odd things in the system we haven't anticipated, but for the time periods we looked at, especially to 2100, we don't see that.

Mr. BARTLETT. Thank you.

Chairman GORDON. The gentleman's time has expired.

Chairman Miller is recognized for five minutes.

TROPICAL STORMS

Mr. MILLER. Thank you, Mr. Chairman.

Dr. Trenberth, the IPCC Report and your testimony both referred to one result of global climate change, global warming, as being the intensity of tropical storms. In the fall of 2005, after the hurricane season that we had that included Katrina, of course, and several other catastrophic storms, Category 4 and Category 5, I can't recall how many, but several, and they were stunning to look at in the satellite view of how large and perfectly symmetrical they were. The press wondered whether there was a relationship between global climate change or global warming and that hurricane season. And many made many requests of NOAA and NOAA produced a hurricane scientist named Chris Landsea, who treated those questions as if they were an urban legend and was very dismissive of that possibility. And as a result, the press kind of went away on that topic and concluded that was not serious science that anyone had that question. In fact, there were others within NOAA, other scientists, who said that yes, the formation of the tropical storms may be cyclical, as Dr. Landsea had said, but the intensification is very much related to temperature. What was the state of the science in the fall of 2005 and what is it now on the relationship between the intensity of tropical storms and water temperature?

Dr. TRENBERTH. Indeed, the 2005 season, in fact, it began a little before that, even with the 2004 season where four hurricanes hit Florida and there were ten typhoons that ended up hitting Japan, have raised this question, and there has been a great deal of research that has gone on even after our report, although our report, I think, is still a fair assessment of the current situation. And we had a breakout group that dealt with this in Paris, and the statement on page 8 of the SPM is fully consistent with all of the literature that we have reviewed in our report. And maybe I should read it. It says, "There is observational evidence for an increase in intense tropical cyclone activity in the North Atlantic since about 1970, correlating with increases in tropical sea surface temperatures." This is one thing where there is widespread agreement that if the sea temperatures go up, you get more activity. And we are seeing that in the North Atlantic. And then the second question is why are the sea temperatures going up. And certainly, on a global basis, we know that there is a component of that. We believe it is close to about one degree Fahrenheit now associated with the increases in greenhouse gases. And then you can argue about how much of that is occurring in the hurricane regions and so on. There is some natural variability.

Another key part of our statement also recognizes that "multidecadal variability and the quality of tropical cyclone records prior to routine satellite observations in about 1970 complicate the detection of long-term trends in tropical cyclone activity." And so this is saying that, indeed, a lot of natural variability as well as the greenhouse gas-induced trends that are playing a role, and in addition, the database that we have is not as good as we would like. And so there are some uncertainties there. But nonetheless, there has been an increase in activity.

Now the theoretical understanding suggests that, indeed, there will be an increase in activity of some sort, and that can be manifested in a number of ways. You can have increased numbers, increased intensity, increases in size, increases in duration. And we don't have measures of all of those. They are not in the historical record. We don't have measures of size adequately. And so this is a very important question, but there are a number of uncertainties that remain.

SOCIAL AND ECONOMIC IMPACTS OF CLIMATE CHANGE

Mr. MILLER. Okay. One more question for any of you who wish to answer.

There have been several references to economic consequences dealing with greenhouse gases in opening statements and in some of the questions that were propounded to all of you. Last fall, the British government released an economic report by Sir Nicholas Stern, who is a former World Bank economist, a 600-page report that I admit to not having read. But it concluded that global warming could leave millions homeless and result in as much as a $7 trillion, or 20 percent diminution in the size of the world's economy and cause the greatest market failure—greatest economic failure in the world's history comparable to the Great Depression and worse than the Great Depression, worse than the world wars. Knowing what you know about the consequences of global warming of the forecast, does that sound right?

Dr. SOLOMON. I would really urge you to wait for the Working Group III assessment. Those are the people who would be qualified to make that kind of statement. Also, Working Group II, I believe, will be dealing with that. This is simply not something that is covered in the Working Group I reports. Sir, I am sorry, but we don't have the expertise to respond to this question.

Chairman GORDON. The gentleman's time has expired. Dr. Ehlers is recognized for five minutes.

MORE ON THE IPCC PROCESS

Mr. EHLERS. Thank you, Mr. Chairman, and first of all, just a little housekeeping. I did a quick calculation on the question Mr. Rohrabacher asked, and my estimate is that 35 percent is the answer.

The other comment I wanted to make, Mr. Chairman, is that I personally appreciate the fact that the Speaker of the House appeared before this committee and made some comments. First of all, this is an extremely important issue, but also I think that any time the leadership pays any attention to this committee is good because sometimes—personally, not publicly—this is the first time I said it publicly, but sometimes I think this is the Rodney Dangerfield Committee. We do incredibly good work here and don't get the respect we should. So I hope this is a sign——

Chairman GORDON. We had a lot of bills on the Floor today——

Mr. EHLERS. I know.

Chairman GORDON.—yesterday, and previously that I think will demonstrate that Rodney is out of town.

Mr. EHLERS. I hope that he has moved out permanently.

Having said all of that, just first of all, I want to thank you for being here. A quick question anyone could answer: this is of course a summary that you have prepared. When will the full report be published? Do you know? Dr. Solomon?

Dr. SOLOMON. The full report is being copy-edited and laid out. It will be available probably around May.

GLOBAL IMPACTS OF CLIMATE CHANGE

Mr. EHLERS. All right. Thank you.

Just a few quick comments. First of all, I think it is very clear that global warming is occurring, and we can argue about how much and the causes and so forth, but it is occurring. The next question is it anthropogenic? It definitely seems to be, either through industrialization or through farming, as we have heard.

A couple of questions: what about global climate change, by which I mean the whole picture? We seem to be obsessed here this morning about global warming, but I am much more worried about climate change. For example, I am from Michigan. We would certainly welcome a bit of global warming in Michigan, especially this past weekend when I got up Monday morning and it was nine-below with a wind chill of 21-below. But I wouldn't want global warming at the expense of losing rainfall in Michigan and having it turn into a place like Kansas or—I guess I can say Texas since our Ranking Member isn't here.

That really points to the political difficultly we have. We have two political problems. One is, if we are talking just about global warming, which is related to human activity, industrialization particularly, that is an immense political problem, globally, to try to get people to cut back. And I was opposed to the Kyoto Agreement because it gave a free card to China, and I knew China was going to be one of the biggest contributors. So that is one political problem. The other one is that global climate change is going to be good for some areas of the planet and bad for other areas of the planet.

Now, how far along are you in determining the effects of global climate change and the impact that it is likely to have on different parts of the globe? How far along are the models in determining that and with what accuracy?

Dr. MEEHL. This is sometimes referred to as the winners and losers issues. We didn't really address that in the Working Group I Report. That is really a Working Group II impacts question. But when I get asked this question—you know, we have said a lot about changes in weather and climate extremes. And one of the changes we have seen in extremes lately is a decrease in the number of frost days, in other words, nighttime temperatures going below freezing. This is something we have already observed, and in the models, we project this to increase in the future, that you will have warmer nights, and less nights below freezing.

So you can say, well, maybe that is a good thing because maybe that will expand the growing season length, and we do show in the report that the growing season gets longer because of that. You have later frost in the fall and then earlier warming up in the spring. But then there are things like insect infestations that are affected because, if it doesn't get as cold in the winter, you don't kill off as many of the bugs in the wintertime. They live though the winter, and then you have severe problems with insect infestation. Out in Colorado, we have seen a lot of problems with that with pine beetle kill.

So it is kind of a mixed bag, a lot of times. There are some things that may be better, but then there are other unforeseen consequences, and I think that is what makes me, personally, nervous because when we are moving into a new regime, which we are, which we have never really observed before, there are things that we can anticipate that could have good consequences, but other things that have bad consequences. And that is the part, at least, that hopefully Working Group II will address in more detail.

Mr. EHLERS. Well, that is precisely my concern because in our arena—now, I am a scientist, but I ended up in this arena. That is where the decisions are made in those issues, and we need the information to make intelligent decisions, and the sooner you can develop comprehensive models that can deal with those issues, the better off we will be in this arena.

Chairman GORDON. Thank you, Dr. Ehlers. You got bonus time for nice comments. Mr. Lipinski is recognized for five minutes.

MANAGING WATER RESOURCES

Mr. LIPINSKI. Thank you Mr. Chairman. Thank you for holding this hearing on this very important topic that I am very hopeful will move forward in this Congress in a bipartisan fashion. I am working on this issue, and I appreciate the testimony that all of you have given. I understand that your role here is to talk about the science behind what is going on. In the future I am sure we will have many panels where we will talk about what can be done to mitigate this, but than you for bringing you expertise to us today.

I want to ask—I am from the Chicago area, and I represent part of Chicago, and I want to ask Dr. Trenberth: you talked about managing water resources in the future as climate change progresses. Now, I am just wondering if there is anything you can tell us, perhaps not, but I was wondering if there was anything you could tell us about how these atmospheric changes may effect Chicago and other areas like that. I mean Chicago uses about two billion gallons of water per day, from Lake Michigan. Is there anything you can tell us about that?

Dr. TRENBERTH. As the climate warms, the water-holding capacity of the atmosphere goes up about four percent per degree Fahrenheit, and we find from the observations that this is actually happening over the ocean. Over the land, it is happening at a slightly less rate. But it means that there is more water vapor in the atmosphere. Now when you have a storm, the storm reaches out and grabs the available water vapor, concentrates it and dumps it down in the form of rainfall. So with more water vapor in the atmosphere, you expect that when it rains, it is going to rain harder, or even when it snows, it can snow harder, and that is what we are actually seeing. And so you get heavier rainfall events. This is what is also predicted in the models. However, when that happens, you also deplete the water vapor in the atmosphere, so you change the frequency of these events, and it may be that they are more intense but they may be a little bit fewer and farther in between, and so you have a greater risk of drought in between. There is a little bit of extra heat available, so the drying effects of that exacerbate drought.

Ironically, then you get both extremes of what we call the water cycle that are affected by global warming, and it means that the challenge of water resource management is that they have times when they have got too much of a good thing, too much rainfall, a risk of flooding, and then there are times in between when they don't have enough. This is particularly what that comment refers to: the changing character of precipitation, the changes in snow to rain, it also means that you have less snow pack going into the spring and summer, which is when you most need the water, so that aspect of management is another key part of it. And so these are the factors that play into the water management challenge.

More on Climate Research

Mr. Lipinski. Thank you, and I want to ask Dr. Alley, you mentioned that the apparent shrinking of the large ice sheets was an unexpected finding. Why was this unexpected and can you point out any other findings that came out as a big surprise to you?

Dr. Alley. We had a longstanding debate in the community. How fast can ice sheets do interesting things? They are very large; they look sluggish. And yet you look back at the history of the climate, back to the Ice Age, and most of the time ice sheets were boring, and occasionally they were really interesting. And so we have had this longstanding debate in the community are the ice sheets going to be boring or they going to be interesting, and the assessed science of the report said the most likely outcome is boring, and they have been interesting, and that, probably, for me was the most surprising thing that came out of it.

The other thing that I see, looking at the report, is how good the science has become on so many things. So the early IPCC reports picked out sensitivity. You are at double CO_2. How much does the climate warm? And it was based on moderately weak evidence. It was good science, but there just wasn't a lot of it. And as the amount of science has been produced, as more research has been done, more models, more observations, the quality of the support, the strength of the conclusions has just become tremendously greater. So there are a few, you know, gaping holes that we would love to fill, but primarily the quality of the science is just superb. It is just outstanding, and results are getting to the sort of pound-on-the-table-this-is-right stage. Thank you.

Chairman Gordon. The gentleman's time has expired. I am told that the gentleman from South Carolina, Mr. Inlgis is next and recognized for five minutes.

OPPOSITION TO CLIMATE CHANGE

Mr. INGLIS. Thank you, Mr. Chairman. I am one of those people that used to poo-poo global warming. It seems to me it is hard not to be persuaded with the evidence that you have been talking about. There is always the question of causation, so I would make the analogy to the doctor who determines it is genetics that determines longevity. Doctor, would it hurt us to diet and exercise? Not likely to hurt us. So it is not likely to hurt us to take some action, as long as we can do that in a way that maintains balance with other things that we have got to do in life, like make a living and provide for our families and all of those kinds of things. So it seems to me the key is to work cooperatively to solve some of these challenges.

It is going to be hard, though. I read yesterday, Mr. Samuelson's piece, Mr. Chairman, that I asked to insert in the record. It is Robert J. Samuelson, "Global Warming and Hot Air." And basically describes just how difficult it is going to be and address the challenges at hand. But there are some real opportunities, for example, reinventing the car so that it runs ultimately on hydrogen, let us say, or batteries, or something that doesn't emit CO_2. What an exciting opportunity for us to make money, which is great thing too, and to clean the air, and to improve the national security of the United States. But it is going to be hard.

I think we made progress here, today, Mr. Chairman, with the Speaker's open-mindedness to looking at nuclear power. That is a very significant development here today, I think. And it shows a level of cooperation I think we all need to have: come with open minds about how to solve this challenge.

Part of the change in my thinking came from a wonderful trip to Antarctica about this time last year with a number of Members who are here today, led by Sherwood Boehlert, and perhaps one of you can help me relearn what I think I learned there about the methodology of the ice cores, the drillings, and what we found there. Can somebody describe that so I can relearn, and maybe, I can just learn?

Dr. ALLEY. Happily. I have worked on ice cores in many places, Antarctica and Greenland, and essentially an ice core is like a really fancy drill. If you were going to put a knob in your door, you would just take a pipe with teeth on the end, you would spin it, you would run it down, you pull out a piece of ice, and you would do that until you have two miles of it. And if you break the bubbles, that is a little bottled sample of old air. You can find out whether carbon dioxide was higher or lower in the past. Very high confidence that this works. It matches the instrumental record over recent times, different cores from different places with different temperatures and different snowfall rates give the same answers. And so what shows is that the level of carbon dioxide, the level of greenhouse gasses that we have in the atmosphere, are unprecedented, at least for the last 650,000 years.

Mr. INGLIS. And going back to some earlier questions. What is the chance of that happening as a result of natural phenomena, that significant increase?

Dr. ALLEY. If one looks at a long record like that and says, well, it surely looks now like we are above what nature has done for the last 650,000 years, and it happened in the last 1000, that would seem unlikely. In addition, we very clearly—oil companies are quite good; they know how to find oil. Coal companies are quite good; they know how to find coal. And we know how much they found, so we know how much is being burned. We know how much carbon dioxide is going into the air, and we know where it is going, and sort of our fingerprint is on this with very high confidence.

Mr. INGLIS. For those who dispute that, what is their best argument? Where can they find some data besides what you just reported on?

Dr. ALLEY. I truly don't know what a really good argument is against this. There are a number—we have the budget. We know what is going up, what is going down. But then you can ask, well, is there evidence of that? Maybe your budgeting is wrong. And then you say—but carbon isotopic composition of fossil fuels is different than the carbon isotopic composition that was in the air. And we can see the change over time as humans are putting fossil fuel CO_2 up. That applies both to the stable carbon and to the radioactive carbon. We are diluting the natural radiocarbon in the atmosphere by putting old carbon up from below. One can see the very, very tiny change in oxygen composition that goes with burning the fossil fuels. So once you say, well, we know the budget, then, someone will say, well, are you are right about that. Then, you say, well, if we are right, then you should say this in the stable carbon, you should see that in the radioactive carbon, you should see the others in the oxygen, and you see all of those.

Chairman GORDON. The gentleman's time has expired. The Gentleman from Kentucky.

Mr. INGLIS. Mr. Chairman, a reminder to insert that in the record, the Samuelson piece, without objection?

Chairman GORDON. Without objection.

[The information follows:]

INFORMATION FOR THE RECORD

Global Warming and Hot Air

BY ROBERT J. SAMUELSON

Washington Post

WEDNESDAY, FEBRUARY 7, 2007; A17

You could be excused for thinking that we'll soon do something serious about global warming. Last Friday, the Intergovernmental Panel on Climate Change (IPCC)—an international group of scientists—concluded that, to a 90 percent probability, human activity is warming the Earth. Earlier, Democratic congressional leaders made global warming legislation a top priority; and 10 big U.S. companies (including General Electric and DuPont) endorsed federal regulation. Strong action seems at hand.

Don't be fooled. The dirty secret about global warming is this: We have no solution. About 80 percent of the world's energy comes from fossil fuels (coal, oil, natural gas), the main sources of man-made greenhouse gases. Energy use sustains economic growth, which—in all modern societies—buttresses political and social stability. Until we can replace fossil fuels or find practical ways to capture their emissions, governments will not sanction the deep energy cuts that would truly affect global warming.

Considering this reality, you should treat the pious exhortations to "do something" with skepticism, disbelief or contempt. These pronouncements are (take your pick) naive, self-interested, misinformed, stupid or dishonest. Politicians mainly want to be seen as reducing global warming. Companies want to polish their images and exploit markets created by new environmental regulations. As for editorialists and pundits, there's no explanation except superficiality or herd behavior.

Anyone who honestly examines global energy trends must reach these harsh conclusions. In 2004, world emissions of carbon dioxide (CO_2, the main greenhouse gas) totaled 26 billion metric tons. Under plausible economic and population assumptions, CO_2 emissions will grow to 40 billion tons by 2030, projects the International Energy Agency. About three-quarters of the increase is forecast to come from developing countries, two-fifths from China alone. The IEA expects China to pass the United States as the largest source of carbon dioxide by 2009.

Poor countries won't sacrifice economic growth—lowering poverty, fostering political stability—to placate the rich world's global warming fears. Why should they? On a per-person basis, their carbon dioxide emissions are only about one-fifth the level of rich countries. In Africa, less than 40 percent of the population even has electricity.

Nor will existing technologies, aggressively deployed, rescue us. The IEA studied an "alternative scenario" that simulated the effect of 1,400 policies to reduce fossil fuel use. Fuel economy for new U.S. vehicles was assumed to increase 30 percent by 2030; the global share of energy from "renewables" (solar, wind, hydropower, biomass) would quadruple, to eight percent. The result: by 2030, annual carbon dioxide emissions would rise 31 percent instead of 55 percent. The concentration levels of emissions in the atmosphere (which presumably cause warming) would rise.

Since 1850, global temperatures have increased almost one degree Celsius. Sea level has risen about seven inches, though the connection is unclear. So far, global warming has been a change, not a calamity. The IPCC projects wide ranges for the next century: temperature increases from 1.1 degrees Celsius to 6.4 degrees; sea level rises from seven inches to almost two feet. People might easily adapt; or there might be costly disruptions (say, frequent flooding of coastal cities resulting from melting polar ice caps).

I do not say we should do nothing, but we should not delude ourselves. In the United States, the favored remedy is "cap and trade." It's environmental grandstanding—politicians pretending they're doing something.

Companies would receive or buy quotas ("caps") to emit carbon dioxide. To exceed the limits, they'd acquire some other company's unused quotas ("trade"). How simple. Just order companies to cut emissions. Businesses absorb all the costs.

But in practice, no plausible "cap and trade" program would significantly curb global warming. To do that, quotas would have to be set so low as to shut down the economy. Or the cost of scarce quotas would skyrocket and be passed along to consumers through much higher energy prices. Neither outcome seems likely. Quotas would be lax. The program would be a regulatory burden with little benefit. It would also be a bonanza for lobbyists, lawyers and consultants, as industries and localities besieged Washington for exceptions and special treatment. Hello, influence-peddling and sleaze.

What we really need is a more urgent program of research and development, focusing on nuclear power, electric batteries, alternative fuels and the capture of carbon dioxide. Naturally, there's no guarantee that socially acceptable and cost-competitive technologies will result. But without them, global warming is more or less on automatic pilot. Only new technologies would enable countries—rich and poor—to reconcile the immediate imperative of economic growth with the potential hazards of climate change.

Meanwhile, we could temper our energy appetite. I've argued before for a high oil tax to prod Americans to buy more fuel-efficient vehicles. The main aim would be to limit insecure oil imports, but it would also check CO_2 emissions. Similarly, we might be better off shifting some of the tax burden from wages and profits to a broader tax on energy or carbon. That would favor more fuel-efficient light bulbs, appliances and industrial processes.

It's a debate we ought to have—but probably won't. Any realistic response would be costly, uncertain and no doubt unpopular. That's one truth too inconvenient for almost anyone to admit.

Mr. INGLIS. Thank you, sir.

Chairman GORDON. Mr. Chandler from Kentucky is recognized for five minutes.

Climate Change Scenarios

Mr. CHANDLER. Thank you, Mr. Chairman. I do not need to be persuaded. I think I can see facts rather clearly when they are presented. I had the opportunity, along with the gentleman from South Carolina, to go on that Congressional Antarctic sojourn last year, and it was a truly eye-opening experience. We saw a lot and, I think, got a pretty clear picture of what the science—at least the science that people were working on down there—showed. One thing that is abundantly clear is what the graphs show in the last handful of years, and that is shocking, truly shocking, to see the change in terms of warmth in the atmosphere in a really surprisingly short period of time. And frankly, it is just hard for me to imagine that fossil fuels can be deposited in the Earth over hundreds of millions of years and can be released in the amounts that they have been released in, in a very short period of time, without having some dramatic effect on the atmosphere. It just goes against any sort of reasonable thinking.

And I would like to know, can you give us any idea about how quickly you feel this process is going to speed up in the near-term, this warming process? It has been quite dramatic in the last decade or two. Do you look for that speed, that sort of dramatic uptake to continue in the next couple of years? Do you think it will speed up exponentially?

Dr. MEEHL. Well, I think what we have seen from the scenarios we have run with the models is that pretty much no matter scenario we are on, the next 20 or 30 years, the warming is going to be about two-tenths of a degree centigrade, per decade. And of course, that is barring any huge volcanic eruption that would cool it down for a year or two. But from the anthropogenic or human-caused part, we are on a track now for another, for about two-tenth of a degree C warming over the next few decades. But having said that, when you get past about the 20s, 30s, then you will start seeing the scenarios really starting to spread.

Mr. CHANDLER. You mean a big spike?

Dr. MEEHL. A spreading out. The high emissions give you more warming and the low emissions give you less warming. So we kind of have this very consistent warming no matter what scenario we are on for the next 30 years, and then you start seeing the spread. But having said that, it does make a difference what track we are on because we are setting ourselves on a course now to follow one of these outcomes and depending on if we are on a high-emissions outcome, we are going to get a lot more warming. If we are on a low-emissions outcome, we are going to get less warming. So I think what we do now does make a difference for the future.

More Climate Change Scenarios

Mr. CHANDLER. Now, I would like to ask a question about the ice. Dr Alley, you have mentioned something on ice sheets being boring. The same, certainly, cannot be said about you. I can't help but ask, what do you think is going to happen? I heard predictions of dire results in the Arctic, among other places, largely because, as I understand it, because there is no land up there, and that makes a big difference in all of the forces that are involved there. Can you make some kind of a prediction about what you think is going to happen to the Arctic and how quick you feel that result will occur if we do nothing?

Dr. ALLEY. There are a number of assessed-model results in the report looking at the sea ice of the Arctic Ocean, which is the frozen ocean water, and I don't have the quota in front of me, but some of the extreme warming scenarios in some of the models get to a no-sea-ice in the summer in the Arctic at the end of this century, so fairly large changes showing up in the frozen ocean water.

Mr. CHANDLER. All gone?

Dr. ALLEY. For the late summer, in the more extreme warming scenarios, in some of the models, and it would grow back in the winter in those models. So that is the floating part. Then, the part that is not yet floating, up on Greenland, almost certainly is there yet in the end of the century, but in the larger warming is melting fairly rapidly at that point.

Mr. CHANDLER. Which would almost certainly have an impact on things like the Gulf Stream. A kind of huge impact, wouldn't it?

Dr. MEEHL. Not so much on the Gulf Stream. I think it is more on sea level raise. Because in the projections, where models have included melt from the Greenland ice sheet, like I was explaining before, it does contribute to slowing down this overturning circulation, but it doesn't ever actually stop it. But I think the biggest concern, and something Dr. Alley alluded to, is how unstable something like the Greenland ice sheet is. And this again is in this category as we are moving into an era where we are starting to observe things we have never seen before in recorded human history. Glaciologists have talked about the possibility of rapid ice-sheet destabilization as a possibility. They have talked about a possible mechanism. In the last ten years, they started to make observations that maybe this mechanism actually is working. But because we have a very short time period when we have actually observed this kind of possible instability, we don't know what to make of it. Like Dr. Alley said, is it a temporary thing? Would it be sustained or accelerated more in the future? And we just don't know. And I think that falls under the category of things that we can with certainty and other things that we just don't know about right now. This is obviously being researched, and a lot of scrutiny is being put on this now, so we will have better answers in the next few years, but right now, we just don't know.

Chairman GORDON. The gentleman's time has expired, but I would assume that there is no good news. It is only bad news that will be coming from this. The Gentleman from Florida?

SCIENTIFIC CONSENSUS

Mr. DIAZ-BALART. Thank you, Mr. Chairman. First, I want to thank you for putting this hearing together. I think you brought some great witnesses. I also want to thank the Speaker. It is always good to bring attention to issues, so obviously, she honored us this morning.

You know, I am pretty much like Mr. Inglis is, like Congressman Inglis. I have gone from not knowing much about it, just because you know, you see Hollywood movies, and that kind of scares me. The more you read—and being one that always has to—I think we all have to—obviously, since we aren't all scientists, we have to rely on the real science as much as possible, so what I keep hearing more of is that that is where real science is certainly going.

I am asking for some reassurance to make sure that I am leaning in the right direction. I tell you that before, for example, the more I read—let me just quote this one thing from the press, "As for the present trend, a number of leading climatologists have concluded that it is very unpleasant news, indeed." They say that it is the root cause of a lot of the unpleasant weather around the world, and they warn that it carries potential for human disasters of unprecedented magnitude. I keep hearing about this possibility because of global warming.

What scares me sometimes is that that is not about global warming. That is an article in *Fortune* magazine from 1974 about climatologists now blame those droughts and floods on global cooling trends. I also have, then, from the Washington, January 1970. "Is mankind manufacturing a new Ice Age for itself?" And it quotes a number of prestigious scientists who, now, are some of the ones who believe that they were wrong then and now that we are going to global warming. "Winter held dawn of new Ice Age," this is from the *Washington Post. Science Digest,* "Brace yourself for an Ice Age."

If we would have obviously gone ahead and acted because of what a number of very prestigious scientists would have said then, we would have been dead wrong—because I have to believe you all. I really do. I happen to believe you all. So what I am asking for is reassure me that in 1970 we were still looking at science that the world was flat and that prestigious scientists were dead wrong, because that is what I believe because that is what I hear. And now science has changed dramatically and technology, which is what I think I have heard today—and that therefore that is wrong, and that the new consensus that we are in a warming trend is correct, and that therefore I can feel comfortable with that point of view.

Dr. ALLEY. I will try first, and then maybe my colleagues will help a little bit.

Mr. DIAZ-BALART. And if I may interrupt you, Mr. Alley, I am also resentful of the fact that you made me very hungry this morning with your pancake analogies. It is 12:30, and I think that is unfair.

Dr. ALLEY. I apologize for that, yes. We are with you on that one, actually.

As scientists, you know, our job is to push the limits. I teach at a very large school, and I can assure you that there are a lot of very bright students there that are pushing the limits. They are coming up with new ideas that are going to help us and save us, and some of it is totally off the wall. And so as scientists, we bubble up all of these interesting ideas, and then you have built mechanisms, we have built mechanisms, the world has built mechanisms, to distill all of these ideas into something which is policy-relevant for you. And so this global cooling, which some of it came from us learning to understand the Ice Age, and some it came from a lot of aerosols coming out off smokestacks, blocking the sun, was something that was bubbled up in a little bit of discussion and huge amount of press interest. But if you go back and ask if the National Academy actually come out with a global-cooling warning, you won't find it. You know, when you get to the point of asking was the assessed knowledge that was pulled together policy relevant for you? Was that warning about this? Was that the big issue? I don't believe you will find it. And so the IPCC here exists as a mechanism, as does the National Academy. It exists as a mechanism to take all of these wonderful ideas, this ferment and froth that is out there in the scientist community, and say what stands up, what is reliable, and to give it to you. And we are here to tell you that the assessed science of the world is pointing to human activities, changing the atmosphere in a way that is causing warming.

Mr. DIAZ-BALART. And I appreciate that.

Mr. GILCHREST. Will the gentleman from Florida yield just for two seconds on this time?

Mr. DIAZ-BALART. Of course.

Mr. GILCHREST. Having lived through that period of time, and having read a number of articles and books, born in the 1970s, Dr. Alley is correct, there was not a consensus that we were cooling. There was some suggestion, for a variety of reasons—the consensus was are we cooling or warming. We don't know yet. So at that point, there was no consensus.

Chairman GORDON. The gentleman's time has expired.

Mr. DIAZ-BALART. Could I have a ten-second comment?

Chairman GORDON. With unanimous—we will see if I can get this unanimous consent. I wasn't able to get one earlier.

Mr. DIAZ-BALART. Mr. Chairman, I just learned—is it possible that the press exaggerates on issues? I am just shocked at what I learned today in this committee. I can't believe that. I am sorry. I just can't believe that.

Chairman GORDON. Okay. Thank you, Professor—or Doctor, was it? I guess it was Inspector Reneau. And a very patient gentlelady from Arizona, Ms. Giffords, is recognized for five minutes and ten seconds extra if she needs it.

IMPACT ON THE SOUTHWESTERN UNITED STATES

Ms. GIFFORDS. Thank you Mr. Chairman. First of all, I want to thank all of you for coming. It is important that you are here. We appreciate that you are here. The American people are glad you are here, and frankly, the world is. This is an area that I so passionately believe that we need to lead in. And I look around at all of the portraits behind you, particularly that depict America's mission to go to the Moon and to explore space and where we lead. And that Apollo mission of the future, I believe, is in energy and climate change. And this is just a first start. Mr. Chairman, thank you for bringing such distinguished speakers here today, and we appreciate your science. We may all not agree, but this is a process where we deliberate, and I just certainly appreciate being here.

My question reflects my district, which is Southern Arizona, the most extraordinary district. If you can, imagine Tucson going all of the way to New Mexico. And this is an area—we are not sure quite, but eight or nine years of a drought we are experiencing. We are also seeing some other strange changes that we have just not seen before. We had a very strange storm happen about a year-and-a-half ago that produced some rockslides in our mountains that we are not familiar with. We also had some wildfires in Arizona, particularly in the Catalina mountain range, that burned very hot, we understand, that because of the weevil infestation that has been allowed to build up, because of it not freezing, and the trees then weakening. So I am just curious and as a former legislator, I tried to establish a climate-change study group in the Arizona legislature. We brought some distinguished scientists from the University of Arizona, where they have a global climate center, and frankly, my colleagues on both sides of the aisle were not polite to the scientists. And even one of my colleagues said well, heck, hot is hot. What is the difference between 115 degrees or 120 degrees? So I ask you, and I am not sure which scientist to address this to, if you could explain in real terms, for the citizens of southern Arizona, the difference between 115, 116 degrees, 120 degrees. What does that really mean in the next five years, the ten years, and 50 years for the people of Arizona?

Dr. TRENBERTH. Well, let me have a crack at this there.

Indeed, the drought in the southwestern parts of the United States from 1999 to 2004 is one of the things which we think may be, indeed, symptomatic of the climate changes that are underway related to global warming. In the winter of 2004–2005, we had weak to moderate El Niño, so there was maybe temporary relief. We are not quite sure. Certainly, the droughty regions have continued since then. But your concern about temperature, there are a number of analogs, and perhaps one of the best analogs is the year 2002 which is when the drought in the West and in the Southwest was most extensive. And one of the things that goes along with the drought is higher temperatures and heat waves, and in particular, one of the consequences is wildfires. And the risk of wildfires went up in 2002, there were a very large number of wildfires. In fact, I don't know what the cost of those was; I do know there was over a quarter of a billion dollars spent just in fighting the wildfires alone. And so that is one of the risks that goes along with the increases in drought and increases in heat waves.

Dr. MEEHL. Let me just add that the Southwest U.S. is actually an area that we saw some interesting results when we looked the model projections for extreme events, and you mentioned rainfall. That's an area that shows that when it does rain, in future projections, it rains harder, but there are actually more days in between rainfall events. So the dry spells in between rainfall events increases, but when it does rain, it rains really hard. But when you average those changes over a season, the average rainfall is still less in the future projection. So in that area, in the Southwestern U.S., is one area that is most consistent for this kind of result where you just see a change in the nature of the precipitation, how it falls, and how intense it is when it does rain.

REGIONAL VS. GLOBAL MODELING

Ms. GIFFORDS. Dr. Meehl, if I can follow up with you concerning the difference between regional modeling and global modeling. Can you talk a little bit about the regional models and how long it is going to take them to catch up, globally?

Dr. MEEHL. Yes, there is whole class of models that we can imbed, various high resolution regional models in the global models, so we have better representation of the mountain ranges and things like that. This can be very important in regions where, like in Colorado where I am from, where you have big mountains, or in Arizona, you see the mountain ranges and where you get almost locally specific rainfall regimes depending on how the mountain ranges are. We can imbed these models in the global models and get more information on smaller space scales. But those regional models really depend on good global models to drive them. And it is kind of the old garbage-in, garbage-out adage for computing. So if your global model is bad, your regional model is not going to do much better. But if the global model is improved it can drive the imbedded regional model in a more credible way. So that is one of the tools that we can use to get more regionally specific climate-change information, but it is still just a tool. It is not an end in itself.

Chairman GORDON. The lady's time has expired. I will say that my grandfather used to tell me that the most important road in the county is the one in front of your house. You have learned that lesson also.

Ms. GIFFORDS. And Mr. Chairman, can I just say that if every kid growing up had Dr. Alley as a science teacher, we would have more kids going into science because of your passions, so thank you, Dr. Alley.

Chairman GORDON. So that is why we all want to sponsor and be part of our competitiveness agenda. We are going to do that with more scholarships for more science and math and physical science teachers.

Again, the patient gentleman from Georgia, Mr. Gingrey, thank you for sticking with us.

U.S. LEADERSHIP IN MITIGATING CLIMATE CHANGE

Mr. GINGREY. Mr. Chairman, thank you so much. It has not been difficult sticking with you for almost three hours. I am, as you know, returning to the Science Committee, and so it puts me down in the bottom row.

But Dr. Alley, you had commented that those ice sheets are sometimes—well, most of the time are boring and are occasionally exciting, and I think you might could say the same thing about the Science Committee, those of you have been here this morning. And I think under Chairman Gordon's leadership, it is going to be mostly exciting on the Science Committee. I agree with my colleague who just said in complimenting Dr. Alley and the other panelists who testified on the panel this morning. If you could take the tape of this hearing and play it to the middle school class, I guarantee there would be more young people going into science because this has indeed been very exciting.

Chairman, I think you said there wasn't a lot of good news here. I would say that although it is pretty frightening, the global warming and the sea level and the ultimate outcome of what that might be, well, the good news is it looks like God has given us a lot more time than he gave Noah. Now, Dr. Solomon, that is not your NOAA. That is N-o-a-h.

I wanted to point out, and it is been said by some of my colleagues, that a number of us, actually six on this committee, had an opportunity to go to Antarctica, and that is because of the Science Committee. And I was one of those six, I am very grateful. And it was mentioned today, something, a policy, that when we were on the ice, that we couldn't use aerosols. I now know why. I didn't ask the questions, then. But this has been an outstanding hearing. I am grateful to the panel. I am grateful for the Speaker. It is an historic opportunity for the Speaker of House to come before the Committee and testify. I appreciate her comments, particularly in regard to nuclear power. I do have an answer for one of her concerns and that is where would we store the waste? I would suggest that maybe there is place out in Nevada called Yucca Mountain, but that is an argument for another day.

I do have a question, believe it or not, and Dr. Meehl, I am going to address it to you. There is going to be an upcoming article in Newsweek magazine by George Will. We have talked about this, and I know this is a question that you scientists maybe don't want to address and are maybe not necessarily the experts, and that is for us to do, but basically this is what he says in this article "Inconvenient Kyoto Truth: the United States is able to drastically regulate our manmade, greenhouse gas emissions," 35 percent, as was stated by Dr. Ehlers, "but other large industrial countries like China, Israel and Brazil, do not." Will the United States efforts still achieve a positive effect? Take, for example, that China is set to construct all of those new coal-powered plants by 2030, and they have stated that they have no interest, they aren't going to do anything to regulate their emissions. What will the United States' restrictions do to stem the climate change trends that you outline in the IPCC AR–4 report? And that is my question.

Dr. MEEHL. And again, I am going to have to apologize because I am not an expert in this area, so I really can't give you a good answer for that.

Mr. GINGREY. Well, any one of the four would be grateful.

Dr. TRENBERTH. It will set a good example. I mean I think I think it is a global problem, and U.S. leadership plays a key role, and it does relate then to international pressures to bring everyone in line, I think.

Mr. GINGREY. Anyone else? Dr. Trenberth, I think that is a darn good answer, and I appreciate it, and I too have learned a lot here today and changed my attitude. I began to change that attitude when I went to the ice about a year ago, and that was a great opportunity. I thank you, Mr. Chairman, and I yield back.

Chairman GORDON. Thank you, Dr. Gingrey. In response to your suggestion that we should be able to watch this for children, we can. Compliments of the Science Committee, if you will go to *www.science.house.gov,* you can get the web cast of this hearing, the witnesses' statements, Leader Pelosi's statement, and the Chair and Ranking Member's statement, so that is, once again—get your pencil—*www.science.house.gov*.

I was two out of three today, Mr. Gilchrest, on unanimous consent. The first unanimous consent was to allow you as a former Member of this committee to sit in and ask questions, so we will conclude with those statements or questions with you, sir.

MORE ON CLIMATE SCIENCE

Mr. GILCHREST. Thank you very much, Mr. Chairman. I am very happy to see that none of my Republican colleagues objected to that. I have been on the Science Committee a couple of times in the past, and like many of my colleagues, I have been to the ice, the dry valleys and the magnificent spots down there in the Antarctica, so maybe after this hearing, I might ask my side for a waiver to get on the Science Committee again. It looks like it is going to be a pretty exciting year.

I want to take a few seconds to talk about the economic impact of pursuing a program to reduce greenhouse gases and what that would do. To my colleagues remaining here, we have worked with about a dozen Fortune 500 companies, including DuPont, General Electric, Caterpillar, Lehman Brothers, and so on to work this issue through. Their suggestion, their strong suggestion, is based on the risk factor of investment of doing something and what could happen economically if we don't do something. Their suggestion is that the Federal Government create a goal of reducing greenhouse gases by the year 2050 by 70 percent below 1990 levels and then set up a regulatory structure in which there is a cap-and-trade program and tax incentives. And they say through that structure, they can meet that goal by the year 2050—not only meet that goal, but excel at it based on propensity and ingenuity of the United States technology and efficiency, and improve economic viability by improving situations as far as dependence on foreign oil is concerned and a whole range of other things. So there is a pretty good structure out there to do that.

I have four questions that I would like to ask right up front in case I run out of time. The first one is, you have mentioned, let us say, 10,000 years ago that CO_2 concentrations in the atmosphere was about 180 parts per million. Fast forward about 10,000 years, and you have it at 280 per million. And then you come up to the present day, and it is about 380 parts per million. Now, the most recent introduction of increases from a variety of sources is the burning of fossil fuel. Like one of our colleagues said, we have put in the atmosphere in just a few decades, that it took the natural sources to lock up in the form of fossil fuel over millions of years. Can you make a distinction between the kind of carbon that you get from a volcano or other natural sources and the kind of carbon that you get from burning fossil fuel? Is there a marker that you can see, and do you use that in your equation to determine what it man-induced and what not man-induced?

The second question is can you over, let us say, the last 20 years, maybe the last 30 years, determine the cubic miles, the volume of water, coming off the Greenland ices, and has that accelerated in the last 20, 10, five years.

Chairman GORDON. In all due respect, let us see if we are going to have time to get through those two before we go on any further.

Dr. SOLOMON. On the first one, if I may, the numbers you gave were more or less right, except for the time scales. The time when very much lower concentration of CO_2 were observed is really quite a bit earlier. You have to go back to, really, the ice ages.

Mr. GILCHREST. About 10,000 what were the concentrations?

Dr. SOLOMON. You have to go a little bit farther back, more like 20.

Mr. GILCHREST. 20,000, it was about 180 parts per million.

Dr. SOLOMON. And then when we came out of the Ice Age, it went to about 270. As it said earlier, it stayed at 270 for almost 9.9 thousand years.

Mr. GILCHREST. Really, that is even more incredible.

Dr. SOLOMON. Yeah, you can see that in Figure 1. And then, in the last 100, it went dramatically up to about 380, which is where it is now, and it has not been at levels that high in at least 650,000 as Dr. Alley said.

Your question about a marker is also a very good one. As we talked about earlier, the kind of carbon that you get when you burn a fossil fuel is different in terms of its isotopes than what you get from, you know, say trees or other sources of carbon. So the changes in isotopes are a very key element in demonstrating the human influence. Also, the north-south gradient, we see a difference between the northern hemisphere and the southern hemisphere which is also indicative of the human source in the northern hemisphere.

Dr. ALLEY. And then for the Greenland ice sheet, we have watched some of the glaciers speed up with satellite data and put more icebergs into the ocean, and the Atmospheric Surface Mass Balance Community has been reconstructing snowfall and melting on the ice sheet and has seen a rise in snowfall but a faster rise in melting so that it is losing mass that way. You also see that from satellite.

Chairman GORDON. Excuse me. The gentleman's time has expired. In respect to this committee, this panel has been here for three hours. I know you have another briefing to go to and then you have a hearing in the Senate. The Minority had more than due notice to find someone to rebut you. They were not able to do that either through the scientific community or through the Chamber of Commerce. However, Mr. Rohrabacher has been very studious these last three hours in preparing a rebuttal, and I think it is only fair that we allow him that opportunity.

Mr. ROHRABACHER. Thank you much, Mr. Chairman. First, of all, let me compliment you on putting together a fine panel of experts for us, and I apologize for us in the Science Committee along with the many scientists, who disagree with them and have honest disagreement on this issue. And in fact, I will be placing in the record the names of hundreds of those scientists who disagree with this concept that climate change is caused by human activities. Not that there is climate change, but that it is caused by human activity. And we could have had any number of those scientists, and it was remiss on our part not to have someone here representing a scientific—there are people from MIT and Harvard and many, many respected scientists who disagree with this theory. They should have been here. It is our fault for not getting them here.

Let me compliment you as far as a good panel. I think it is great that Speaker Pelosi was here, and I apologize if I do not believe that the objection that was made reflects in any way the attitude of the other Members of this committee, the Republican Members of this committee. I thought it was fine that she spoke, and we paid her the same respect that paid Newt Gingrich and others who have spoken before this panel in the past.

With that said, I do have very serious disagreement with some of the ideas presented today. And look, the reason I have to push for an answer, and I shouldn't have to actually ask five times before I get an answer on certain questions, that it is important to know how much of the greenhouse gases that exist in our atmosphere were caused by natural occurrences. And that is an important thing because in terms of the weight that you put on the changes that need to be made it makes all of the difference in the world. A small change—and if you believe that, as I do, and I remember Dr. Bartlett, who is also a Ph.D. I might add, and has many credentials on this, nor did he believe was 10 percent. Vern Ehlers said 35. I have heard other science panels who really struggled to say that it was between five and ten percent. With that noted, there is a huge disproportion of natural causes of greenhouse gas. Which means that a small change in the natural causes of greenhouse gases, like volcanoes, would have a much bigger impact than a change of human activity, if we could, indeed, create human-activity change on such a broad scale.

So scientists disagree. I am submitting for the record their names. Also, let me note that many scientists are complaining that their research money has been cut off because they disagreed with global warming concepts, and I will be submitting their names for the record as well.

But there is no doubt that global climate change is happening. The only question is why is this cycle of global climate change, and we have gone through dozen of cycles of global climate change, why is it any different than all the other cycles? I noted during the testimony that was presented, the chart that shows that we are now in a cycle when temperature is going up, that it started at the very end of the mini Ice Age which was a very low point, where temperature had been declining for hundreds of years. So whether or not how dramatic this change will be or what it is caused by, are things that honest people, I think, can disagree with. And I really, personally, having been a journalist, the first thing I was cautioned by is when someone was claiming, "well everybody is on my side or everybody says this or there is a total consensus." Most always when people said that to me during my years as a journalist, it wasn't true. It was that there were honest people who disagreed and there was significant disagreement on such issues, and we don't know what those other cycles were caused by in the past. It could be dinosaur flatulence or—who knows? But we do know the CO_2 in the past had its time when it was greater as well. And what happened when the CO_2 was greater than now? There is been many cycles of up-and-down warming.

So with that said, I think that we have had a great discussion today. We need this discussion because the idea, Mr. Chairman, of having some sort of initiative so that our country creates new energy sources to make ourselves independent and making sure that those energy sources are clean is a totally bipartisan goal. It is. There is no doubt that all of us should want to make sure that America isn't held hostage to foreign energy sources and that when we do develop new energy sources that they are clean. But the question that comes to the heart of the matter is this—I am sorry for pontificating too long in this—when we make that decision as a Congress as to what those energy alternatives will be, we shouldn't be basing on science, if it is wrong science that suggests that global climate change is as big an issue as human health. I would prefer to make sure that when we are becoming energy independent and that we develop new energy sources, that we focus our science on making sure that we take the bad stuff out of the atmosphere that hurts human beings, rather than the stuff that may or may not create a cycle that would make us two or three degrees warmer or less in the future.

So with that, I have had my say. I appreciate the privilege of having a closing statement. I appreciate your leadership on this. You held a great discussion today.

Chairman GORDON. Thank you, Mr. Rohrabacher. I hope you feel better. I think the panel has addressed Mr. Rohrabacher's concern on a variety of occasions, so I won't take your time any more, but I do want to very sincerely thank you for the Herculean effort that you put into this product and for allowing the United States Congress Science and Technology Committee to be your first forum today

I think one of the lessons learned today is something that we all should already know which is sometimes it is tough to be a messenger, but you have a very important message. We are glad you came. The message that needs to go out from this hearing is that 113 nations concurred, including this country, that with 100 percent certainty, there is global warming and with 90 percent certainty it is a result, to a great extent, from human activities.

Thank you very much for being here, and all of the witnesses are dismissed, and the meeting is adjourned.

[Whereupon, at 1:05 p.m., the Committee was adjourned.]

Appendix:

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Susan Solomon, Co-Chair, IPCC, Working Group I: The Physical Basis of Climate Change; Senior Scientist, Earth System Research Laboratory, Office of Oceanic and Atmospheric Research, National Oceanic and Atmospheric Administration, U.S. Department of Commerce

Questions submitted by Representative Ralph M. Hall

Q1. How did you develop the Summary for Policy-makers? For example, did you ask policy-makers what scientific information would be most useful to them and structure the Summary around that information? If not, how did you determine which findings to include in the Summary for Policy-makers?

A1. First and subsequent drafts of the Summary for Policy-makers (SPM) were prepared and revised by a sub-group of authors of the IPCC (2007) Working Group I Report and reflect their joint selection of material that they felt should be presented in order to best summarize the full report.

The list of those scientists is given on the front page of the Summary and includes 33 primary authors (collectively representing each of the 11 chapters of the full report), along with 18 contributing authors.

Drafts of the SPM were also discussed with the entire Working Group I author team during author team meetings. All of the 152 authors of the full report were also invited to provide written comments. Comments were also invited from over 600 experts who had reviewed the rest of the full report. Comments were also invited from governments. The SPM draft was revised by the listed subgroup of authors based upon their evaluation of all comments received.

In the course of the IPCC Working Group I Tenth Session held in Paris from January 29 to February 1, 2007, delegates from 113 countries approved the final SPM on a line-by-line basis. Authors were present throughout this session and were charged with ensuring that all proposed changes to wording in the SPM remained fully consistent with the full report. During this final approval process the Lead Authors also identified a small number of changes to the underlying report that will ensure consistency with the language used in the final SPM or provide additional clarity for policy-makers on matters discussed during the session. None of these changes alter the substantive findings of the report and the list of such changes was made available from the IPCC Working Group I web site after the conclusion of the WG I session (*http://ipcc-wg1.ucar.edu/*).

Q2. It is my understanding that in this IPCC report you associated terms such as "very likely" with numerical confidence levels such as "90 percent probability of occurrence;" but that in previous IPCC reports you did not associate numerical confidence levels with terms such as "very likely." Why did you add in the numerical confidence levels in this IPCC report?

A2. Addressed in joint response.

ANSWERS TO POST-HEARING QUESTIONS

Responses jointly by Richard B. Alley, *Lead Author, IPCC, Working Group I, Chapter 4: Observations: Changes in Snow, Ice and Frozen Ground; Evan Pugh Professor of Geosciences and Associate of the Earth and Environmental Systems Institute, Pennsylvania State University;* Kevin E. Trenberth, *Coordinating Lead Author, IPCC, Working Group I, Chapter 3: Observations: Surface and Atmospheric Climate Change; Head, Climate Analysis Section, National Center for Atmospheric Research;* Gerald A. Meehl, *Coordinating Lead Author, IPCC, Working Group I, Chapter 10: Global Climate Projections; Senior Scientist, National Center for Atmospheric Research; and* Susan Solomon, *Co-Chair, IPCC, Working Group I: The Physical Basis of Climate Change; Senior Scientist, Earth System Research Laboratory, Office of Oceanic and Atmospheric Research, National Oceanic and Atmospheric Administration, U.S. Department of Commerce*

Question submitted by Representative Ralph M. Hall

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A1. It is not the case that numerical confidence levels were introduced for the first time in this report as suggested in the question. IPCC has carefully developed the numerical confidence levels used, and they were also used in the previous IPCC report in 2001 (see footnote 7 of the 2001 Summary for Policy-makers, page 2 of the report). The terms "likely" and "very likely" were used in the 2001 report where each was deemed appropriate by the authors, and the terms "likely" and "very likely" are used in exactly the same way in the new IPCC (2007) report. This was introduced in the 2001 report to avoid the problem that the confidence, uncertainty and likelihood of certain things can be interpreted differently by different readers of the report, so a clearly defined scale aids communication and understanding.

Questions submitted by Representative Jo Bonner

Q1. A Wall Street Journal *article dated Feb. 5, 2007 says that data from the U.S. National Climate Data Center showed that in 2006 the world was only 0.03 degrees Celsius warmer than it was in 2001. This difference is in the range of measurement error and is thus not statistically significant. This data might suggest that the world is not warming as fast as first thought. How do you respond to this data report?*

A1. These data do not indicate any weakness in scientific observations of warming to date or projections of further temperature increase described in the Working Group I report. Natural fluctuations associated with weather and phenomena like El Niño mean that warming trends are only reliably seen over decades, not year to year. The recent history of temperature change includes a general warming trend, most of which is very likely due to the increase in greenhouse gas concentrations, overlaid with year-to-year variability arising from other features of the climate system. The effects of this short-term variability must be separated from the longer-term trend to allow estimation of the size of the trend; the comparison between single-year numbers for 2001 and 2006 does not do so, and so does not produce a scientifically valid estimation of the warming trend. Over the past 25 years the trend is 0.18°C per decade, and the statistical uncertainty puts the value from 0.13 to 0.23°C per decade with 90 percent confidence.

Q2. A report published by the Center for Science and Public Policy and authored by Lord Christopher Monckton shows that a 2001 U.N. assessment has over-estimated the human influence on climate change by at least one-third. Lord Monckton also says that in a 2001 report the U.N. estimated that sea levels would rise three feet by 2100, but in reality he notes that sea levels will rise only seventeen inches. This is a big difference. What do you think this difference shows?

A2. We presume that the reports referenced are the "IPCC Fourth Assessment Report 2007: Analysis and Summary" and the corresponding IPCC Third Assessment Report from 2001. Further, we presume that the claimed "over-estimate" of human influence refers to this statement in Lord Monckton's document: "The U.N.'s 2001 report showed that our greenhouse gas emissions since 1750 had caused a "radiative forcing" of 2.43 watts per square meter. Our other effects on climate were shown as broadly self-canceling. In the current draft, the U.N. has cut its estimate of our net effect on climate by more than a third, to 1.6 watts per square meter. It now thinks pollutant particles reflecting sunlight back to space have a very strong cooling effect."

The values in the 2007 IPCC report actually are very consistent with and thus increase confidence in those from the earlier IPCC report, and show that the previous report did not "over-estimate the human influence on climate change by at least one-third." Primarily because of continuing emissions, the best estimate of radiative forcing of long-lived greenhouse gases has increased from 2.43 watts per square meter in the 2001 report to 2.64 watts per square meter in the 2007 report (obtained by summing the central estimates of the effects from carbon dioxide, methane, nitrous oxide and halocarbons from Table SPM–2 of the 2007 report, corresponding directly to the sum from the 2001 report). This long-lived greenhouse gas forcing is not the total forcing, however, and the effects of ozone and the cooling effects of aerosols must be properly included. The 2001 report did discuss the aerosol effects (in Lord Monckton's words, the "cooling effect" of "pollutant particles"), including direct effects on radiation and indirect effects through induced changes in clouds, but the 2001 report noted that no best estimate could be given for some of these effects owing to large uncertainties. The improved ability to include these effects in the 2007 report represents a scientific advance that more accurately quantifies the human effect on climate, and does not in any way represent a prior overestimate of human influence.

Regarding sea-level rise, the Summary for Policy-makers of the IPCC Fourth Assessment Report states (p. 14) that, if considered for the same time interval and emission scenario, the midpoint of the projected sea-level rise from the Third Assessment Report is within 10 percent of that for the Fourth Assessment Report, and that, had uncertainties been treated in the same way, the ranges in those projections would have been similar. Thus, there is not a big difference. Furthermore, as noted in our response to Question 5, below, any additional contribution to sea-level change from additional changes in the dynamical behavior of the large ice sheets cannot be assessed accurately and was therefore omitted from the quantitative estimates.

Q3. Do you think that more emphasis needs to be placed on the population increases in China and India and the vast migration from rural areas to cities? This increase creates demand for property and increases pollution in the cities. Why do we not focus more on these areas to reduce pollution and stop what you consider global warming?

A3. Our testimony concerned the findings of Working Group I of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, on the physical science basis of climate change. Impacts and adaptation will be considered by Working Group II, and mitigation by Working Group III. The question here goes beyond the scope of our Working Group I report, and beyond our individual scientific expertise. However, different possible future population levels, patterns of development, and energy sources and conversion technologies, among other factors, are considered in the Special Report on Emissions Scenarios (SRES). The SRES scenarios in turn underlie the projections of future climate change discussed in the Working Group I report. The different scenarios, e.g., in Table SPM–2 and Figure SPM–7, therefore provide considerable information on the importance of the factors mentioned in the question.

Q4. A.R. Ravishankara with the National Oceanic and Atmospheric Administration said that if you remove pollutants from the air that act as a cooling mechanism, then the heating effect would be intensified. How do you suggest that we find a medium to which pollutants could be reduced to an extent without harming the cooling effect that they have?

A4. Dr. Ravishankara's statement is fully consistent with the IPCC (2007) report. For a given atmospheric concentration of anthropogenic greenhouse gases, lowering the level of anthropogenic aerosols would produce an additional heating effect. (We interpret "pollutants" in the question to refer to anthropogenic aerosols.) As a corollary to this, the "cooling" effect of current levels of aerosols can be seen in estimates of global-average radiative forcing. As shown in Figure SPM–2 of the Summary for Policy-makers of the Fourth Assessment Report of Working Group I of the Intergovernmental Panel on Climate Change, there is a negative radiative forcing from anthropogenic aerosols, partially offsetting the warming effect of anthropogenic greenhouse gases.

The appropriate policy response to this observation is beyond the scope of our report, and beyond our individual scientific expertise. Climate science and the Working Group I Report can inform policy choices by describing how the climate will respond to given levels of aerosols and greenhouse gases. However, there is nothing inherent to the Earth's physical climate that prevents both anthropogenic aerosols and anthropogenic greenhouse gases being reduced to whatever levels are deemed societally desirable. For instance, by increasing energy efficiency and cutting down on fossil fuel burning, both greenhouse gas and aerosol emissions could be reduced.

Q5. The U.N. Climate Panel estimates that Antarctica will actually increase its snow mass this century. Would this not go against the argument that scientists are making saying that glaciers and polar ice caps are melting as a result of global warming?

A5. We presume that "The U.N. Climate Panel" refers to Working Group I of the Intergovernmental Panel on Climate Change, in which we participated. Our report notes that data show that mountain glaciers have declined on average in both hemispheres, and that losses from the ice sheets of Greenland and Antarctica have very likely contributed to sea level rise over 1993 to 2003. The report states "Current global model studies project that the Antarctic ice sheet will remain too cold for widespread surface melting and is expected to gain in mass due to increased snowfall. However, net loss of ice mass could occur if dynamical ice discharge dominates the ice sheet mass balance" (p. 17) and, with reference to the dynamical ice discharge, "understanding of these effects is too limited to assess their likelihood or provide a best estimate or an upper bound for sea level rise." (p. 17) Thus, increased snowfall is expected in Antarctica, but the trend in overall mass of the ice sheet (including loss by ice flow feeding iceberg calving) is not known. More generally, all glaciers respond to the balance between accumulation of snow and loss by melting or iceberg calving. With warming, the atmosphere can hold more water vapor and thus precipitation is apt to increase. In some areas, a resulting increase in accumulation wins out. However, for most glaciers, in spite of increased accumulation, the melt wins out, but this can vary enormously over short distances depending on the local features.

THE STATE OF CLIMATE CHANGE SCIENCE 2007: THE FINDINGS OF THE FOURTH ASSESSMENT REPORT BY THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC), WORKING GROUP II: CLIMATE CHANGE IMPACTS, ADAPTATION AND VULNERABILITY

TUESDAY, APRIL 17, 2007

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE AND TECHNOLOGY,
Washington, DC.

The Committee met, pursuant to call, at 10:00 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Bart Gordon [Chairman of the Committee] presiding.

BART GORDON, TENNESSEE
CHAIRMAN

RALPH M. HALL, TEXAS
RANKING MEMBER

U.S. HOUSE OF REPRESENTATIVES

COMMITTEE ON SCIENCE AND TECHNOLOGY

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Hearing On:

"The State of Climate Change Science 2007: The Findings of the Fourth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC), Working Group II: Climate Change Impacts, Adaptation and Vulnerability"

2318 Rayburn House Office Building
Washington, DC

Tuesday, April 17, 2007
10:00 AM – 12:00 PM

WITNESSES:

Dr. Cynthia Rosenzweig
Coordinating Lead Author, IPCC, Working Group II,
Chapter 1, Assessment of Observed Changes and Responses in Natural and Managed Systems

Dr. William E. Easterling
Coordinating Lead Author, IPCC, Working Group II,
Chapter 5, Food Fibre and Forest Products

Dr. Virginia Burkett
Lead Author, IPCC, Working Group II,
Chapter 6, Coastal Systems and Low Lying Areas

Dr. Shardul Agrawala
Coordinating Lead Author, IPCC, Working Group II
Chapter 17, Assessment of Adaptation Practices, Options, Constraints, and Capacity.

Dr. Roger Pulwarty
Lead Author, IPCC, Working Group II,
Chapter 17, Assessment of Adaptation Practices, Options, Constraints and Capacity

Dr. Stephen H. Schneider
Coordinating Lead Author, IPCC, Working Group II,
Chapter 19, Assessing Key Vulnerabilities and the Risk from Climate Change

HEARING CHARTER

**COMMITTEE ON SCIENCE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES**

The State of Climate Change Science 2007: The Findings of the Fourth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC), Working Group II: Climate Change Impacts, Adaptation and Vulnerability

TUESDAY, APRIL 17, 2007
10:00 A.M.–12:00 P.M.
2318 RAYBURN HOUSE OFFICE BUILDING

Purpose

On April 17, 2007, the Committee on Science and Technology will hold a hearing on the second section of the 2007 Fourth Assessment Report, *Climate Change 2007: Climate Change Impacts, Adaptation and Vulnerability,* prepared by Working Group II of the Intergovernmental Panel on Climate Change (IPCC). Released in Brussels, Belgium, on April 6, 2007, the summary document highlights the key findings of the comprehensive appraisal of the current state of scientific knowledge on the impacts of climate change on natural and human systems around the world. The full underlying report will be released later this year.

The Committee will hear testimony from six witnesses who were involved in the preparation of the Working Group II Report. The witnesses will discuss the findings of the report and the relationship between current findings and those of past IPCC reports on the state of the science of climate change impacts, adaptation, and vulnerability.

Key Findings of the 2007 Working Group II Report

On April 6, 2007 the Intergovernmental Panel on Climate Change (IPCC) released the second section of its Fourth Assessment Report, entitled *"Climate Change Impacts, Adaptation and Vulnerability."* This second section of the IPCC Fourth Assessment Report builds upon information contained in the previous reports. Working Group II was responsible for assessing the scientific, technical, environmental, economic and social aspects of the vulnerability to climate change of ecological systems, socio-economic sectors and human health. The Working Group was co-chaired by Dr. Osvaldo Canziani from Argentina and Dr. Martin Parry from the United Kingdom.

This report updates information from the Third Assessment Report based on research conducted over the past six years. Providing a comprehensive analysis of how climate change is affecting natural and human systems, Working Group II's report also projects what the impacts of climate change will be in the future and assesses the roles adaptation and mitigation can play in reducing these impacts. The report also contains chapters on specific systems, sectors and regions.

Held from April 2nd through 6th, the 8th Plenary session of Working Group II (WGII) gathered government delegates from more than one hundred countries, together with the WGII Lead Authors. The IPCC-produced documents, including this Summary for Policy-makers (SPM), are consensus documents, meaning that all member governments approve the Summary documents and the underlying chapters before each document is released.

Observed Trends

The Fourth Assessment Report represents a significant expansion in our knowledge of the relationship between climate change and impacts on the planet. The number of studies of observed trends in the physical and biological environment and their relationship to regional climate changes has increased greatly since the Third Assessment Report in 2001. This is the first time that WGII has sufficient information to attribute observed changes in physical and biological systems to human-induced global warming. Despite remaining uncertainties, WGII concluded that observational evidence from all continents and most oceans demonstrates that many natural systems are being affected by regional climate change, with regard to:

- **Snow, ice and frozen ground:** There is high confidence that natural systems are being affected through the enlargement and increased number of glacial lakes, increasing ground instability, rock avalanches in mountain regions, and changes in Arctic and Antarctic ecosystems.
- **Hydrological systems:** There is high confidence of increased run-off and earlier spring peak discharge in many glacier- and snow-fed rivers. In addition, studies assessed in this document show a warming of lakes and rivers in many regions, with effects on thermal structure and water quality.
- **Land biological systems:** There is very high confidence that recent warming is causing earlier timing of spring events, such as leaf-unfolding, bird migration, and egg-laying, as well as poleward shifts in ranges of plant and animal species.
- **Marine and freshwater biological systems:** There is high confidence that the impacts of climate change, including rising water temperatures, changes in ice cover, salinity, and circulation, are causing shifts in ranges and changes in algal, plankton, and fish abundance. In addition, climate change stressors are linked to increases in algal and zooplankton abundance in high-latitude and high-altitude lakes and changes in fish migration patterns in rivers.

Projections of Future Impacts

The report addresses projected future impacts in six different categories and for eight regions.

Freshwater resources are projected to increase at high latitudes and in wet tropical areas and decrease in dry areas in the mid-latitudes and in the dry tropics. This is projected to increase the extent of drought-affected areas. In other areas, heavy precipitation events are likely to increase in frequency resulting in an increase in flood risk. Water stored in glaciers and snow cover is projected to decline. This will reduce water availability to one-sixth of the world's population that relies upon meltwater from major mountain ranges.

Projections for **natural ecosystems** are quite negative. The report concludes that many ecosystems' capacity to adapt to climate change in combination with the other human-induced changes and natural disturbances will be overwhelmed during this century. This is projected to lead to a decline in many systems and a substantial loss of biodiversity and a reduction in ecosystem services (e.g., water and food supply). The uptake of carbon by terrestrial ecosystems is projected to peak before 2050 and then to weaken or possibly reverse. A reversal would amplify climate change by adding more greenhouse gases to the atmosphere. Ocean acidification due to absorption of carbon dioxide from the atmosphere is expected to result in declines in shell-forming organisms (e.g., corals) and the species that are dependent upon them.

Projections for **food production (agriculture and fisheries) and forestry** are mixed over time and for different regions. Global projections for crop productivity indicates that it will increase slightly where local average temperature increases are in the range of one to three degrees Centigrade, but will decline above this range. Commercial timber production is projected to increase slightly in the short- to medium-term, but regional variations around this trend are substantial. Aquaculture and fisheries are both expected to decline overall and the distributions and production of particular species will change regionally. Regional projections for crop productivity indicate increases at mid- to high latitudes for increases in the range of one to three degrees Centigrade. These increases are sustained in some areas and decline in others for further temperature increases. In the seasonally dry regions and the dry tropics, crop productivity is projected to decline. In areas where frequency of droughts or floods is projected to increase, local crop productivity will be lower. This is anticipated especially in areas of subsistence farming in the lower latitudes. It is anticipated that agricultural systems will be the most amenable to applying adaptive solutions to climate change through introduction of new cultivars, alteration of water, fertilizer, and land management techniques.

Coastal systems and low-lying areas are projected to be exposed to increased risks due to coastal erosion and rising sea level. The impacts will be exacerbated by increasing human-induced changes in coastal areas. Adaptation options will be variable with developing countries and small island states facing greater challenges than developed countries. Coastal ecosystems, including wetlands and mangroves will be negatively affected by sea level rise. Coral reefs are also projected to decline due to increased bleaching and other stresses due to increased ocean water temperature. Millions more people are expected to experience flooding every year due to sea level rise by late in this century. This is especially true for people living in the mega deltas of Asia and Africa and people living in small island states.

The costs and benefits to **industry, settlement and society** will be highly variable for different locations and scales, but net effects are projected to be more negative with greater changes in climate. The most vulnerable areas will be coastal and floodplain areas. Economic activities that are most closely associated with climate-sensitive resources (e.g., water, fisheries, some agriculture) will be most vulnerable to climate change. Areas where extreme weather events become more intense or more frequent will experience increased economic and social costs due to each event.

Impacts on **human health** are projected to be primarily negative. While fewer cold related deaths are projected to occur in high latitude areas, increased deaths due to heat stress, floods, fires, and droughts will offset these and exceed them especially in the long-term if adaptive measures are not put into place. Malnutrition is projected to increase in areas where food production will decline and the distribution of infectious disease vectors is anticipated to change in response to changing climate (e.g., mosquitoes and ticks). The balance between positive and negative health outcomes will vary considerably with implementation of adaptive measures through public health prevention programs, infrastructure, health care, education, and economic development.

Regional Impacts

This report summarizes the impacts to specific continents and regions of the world, including Africa, Asia, Australia and New Zealand, Europe, Latin America, North America, polar regions, and small islands. For most of the regions of the world, the projected impacts are negative.

Africa is projected to be one of the most vulnerable continents to climate variability and change. The combination of sea level rise in low-lying coastal areas, declining agricultural productivity across the region due to climate variability and change, and increasing problems of water availability all are projected to create serious constraints for African nations.

Asia is projected to have crop yield increases in some regions (East and Southeast Asia) and crop yield declines in others (Central and South Asia). Coastal areas, particularly the heavily-populated mega-deltas of South, East, and Southeast Asia will be at increased risk due to sea level rise and in some cases due to flooding from rivers. Glacier melt in the Himalayas is projected to increase flooding and risk of rock avalanches from destabilized slopes. Once the glaciers have melted, water shortages will be experienced by populations dependent upon glacier meltwater. Water availability is also projected to be an increasing problem in Central, South, East and Southeast Asia particularly in the large river basins.

Australia and New Zealand are projected to experience increasing water availability problems due to increased temperatures and reduced precipitation in many areas. Some increases in agricultural productivity and forest productivity are projected for Western and Southern New Zealand. In Eastern New Zealand and in much of Southern and Eastern Australia, agriculture and forestry production are projected to decline due to drought and fire. The unique natural systems of this region are projected to decline significantly, including the Great Barrier Reef and Queensland Wet Tropics.

Europe is projected to be negatively affected in nearly all regions. Impacts of current climate changes have been documented for the first time: retreating glaciers, longer growing seasons, shift of species ranges and health impacts due to extended severe heat waves. Negative impacts are projected to include increased risk of inland flash floods, more frequent coastal flooding and increased coastal erosion, continued glacier melting, reduced snow cover and extensive species loss. Many organisms and ecosystems will exceed their capacity to adapt to climate change. Northern Europe will generally fare better than Southern Europe through benefits such as reduced heating costs, increased crop yields and increased forest growth with modest increases in average temperature. Southern Europe will become more prone to droughts and more frequent and intense heat waves. Wildfires and peat fires are projected to increase.

By 2050 **Latin America** is projected to experience replacement of tropical forest by dry savanna in eastern Amazonia and replacement of semi-arid vegetation with arid vegetation as average temperatures increase and soil moisture decreases. There is risk of substantial species loss throughout tropical Latin America. In drier areas, climate change is expected to lead to salinisation and desertification of agricultural land leading to reduced crop and livestock yields in these areas. In temperate areas, soybean yields are projected to increase. Melting of glaciers in the Andes will impact water availability for populations dependent upon meltwater. Sea level rise will increase flooding risks in low-lying coastal areas and increases in surface ocean temperatures are projected to have adverse effects on Mesoamerican coral reefs and related fisheries.

Polar regions are projected to experience reduced thickness of glaciers and extent of glaciers and ice sheets and reductions in permafrost and increases in the depth of permafrost thawing in summer months. These physical changes are projected to have negative impacts on migratory birds and mammals. The reduction in extent of sea ice and warmer temperatures provide benefits for ocean navigation and reduced heating costs. However, coastal erosion and changes in permafrost will impact infrastructure and request investments to adapt or re-locate some physical structures and communities.

Small Island states are particularly vulnerable to reductions in precipitation and sea level rise. Some of the Pacific atoll islands are only a few meters above sea level currently. Sea level risk is projected to worsen the impacts of inundation, storm surge, erosion and other coastal hazards which will put island populations at increased risk during storm events. Fisheries and tourism are projected to be negatively impacted as well. By 2050, many islands in the Pacific and Caribbean will experience water shortages during low rainfall periods.

Below are the projected impacts of climate change for **North America.**

- There is very high confidence that warming in western mountains will lead to decreased snow pack, more winter flooding and reduced summer flows, exacerbating competition for over-allocated water resources.
- Forests are projected to experience longer periods of high-fire risk, and greater increases in the area burned; they will also experience disturbances from pests and diseases.
- Cities currently experiencing heat waves could expect them in greater frequency, intensity and duration over the century. The potential for adverse health impacts grows, and the growing elderly population will be most at risk.
- Coastal communities and habitats will be increasingly stressed by climate change impacts interacting with development and pollution. Losses are projected to increase if the intensity of tropical storms increases, as population growth and rising value of infrastructure in coastal areas increase vulnerability to climate change. Readiness for increased exposure is low.
- Aggregate yields of rain-fed agriculture could increase by five to twenty percent because of moderate climate change in the early decades of the 21st century. Major challenges are projected for crops that are near the warm end of their suitable range.

Responding to Climate Change

Since the IPCC Third Assessment there is growing evidence of human activity adapting to observed and anticipated climate change. For example, climate change is considered in the design of infrastructure projects such as coastal defense in the Maldives and the Netherlands. In Nepal, preventative measures have been undertaken to stop outburst flooding of glacial lakes, and in Australia, substantial efforts are underway to reduce water use and better manage this resource. According to the report, these adaptive measures will be necessary to address climate change impacts as a certain degree of warming is unavoidable due to past emissions.

There are wide arrays of adaptation options available to policy-makers but barriers, limits and costs exist to these strategies reaching their potential. In addition, the vulnerability of certain regions to climate change can be exacerbated by the presence of other stressors such as pollution, poverty, food insecurity, conflict, and incidence of disease. In contrast, sustainable development is discussed by Working Group II as a possible way to reduce vulnerabilities to climate change.

We are committed to some change in climate over the next decade due to past emissions of greenhouse gases and their long residence time in the atmosphere. Even stringent mitigation policies enacted now will not prevent climate change impacts over the next few decades. If emissions of greenhouse gases continue unabated, mitigation policies are necessary to avoid the most severe impacts of climate change. Adaptive measures can avoid some of the most serious impacts of climate change over the next few decades. However, they will not be sufficient to overcome the more serious impacts projected if mitigation actions are not taken. This report suggests a response portfolio composed of multiple strategies including mitigation, adaptation, technological development, and research.

Many estimates of aggregate net economic costs of damages (i.e., the social cost of carbon) from climate change are now available, expressed in terms of the future net benefits and costs that are discounted to the present. Peer-reviewed estimates of the social costs of carbon for 2005 have an average value of $12 per ton of carbon dioxide with a range from $3 to $130 per ton. Furthermore, the impacts of climate change will vary regionally but net costs are very likely to impose net annual costs which will increase over time as global temperatures increase.

Witnesses

Dr. Virginia Burkett, U.S. Geological Society (USGS) Global Change Science Coordinator

Dr. Virginia Burkett served as a Lead Author for Chapter 6 of the report entitled: *Coastal Systems and Low Lying Areas.* Currently, Dr. Burkett is serves as a USGS Global Change Science Coordinator at the National Wetlands Research Center. She completed her undergraduate and Master's degrees in biology at Northwestern State University and obtained her Ph.D. in forestry in 1996 from Stephen F. Austin State University in Nacogdoches, Texas. Dr. Burkett's current research involves climate change impacts in coastal regions and bottomland hardwood regeneration in frequently flooded sites of the Mississippi River Alluvial Floodplain.

Dr. William E. Easterling, Director of the Pennsylvania State University Institutes of the Environment

Dr. William Easterling served as a Coordinating Lead Author for Chapter 5 of the report entitled: *Food, Fibre and Forest Products.* Currently, Dr. Easterling is the Director of the Pennsylvania State University Institutes of the Environment, as well as a Professor in the Geography Department at the university. Dr. Easterling received his training as an economic geographer and climatologist at the University of North Carolina at Chapel Hill. His current research focuses on the potential for agriculture in developed and developing countries to adapt to climate variability and change. In addition, Dr. Easterling looks at issues such as the role of scale in understanding the vulnerability of complex systems, especially agro-ecosystems, to environmental change.

Dr. Roger Pulwarty, Research Associate at National Oceanic and Atmospheric Administration's (NOAA) Climate Diagnostics Center

Dr. Roger Pulwarty served as a Lead Author for Chapter 17 of the report entitled: *Assessment of Adaptation Practices, Options, Constraints and Capacity.* Dr. Pulwarty is a research scientist at the NOAA–CIRES Climate Diagnostics Center in Boulder, Colorado. Dr. Pulwarty's research interests include climate and weather, their role in society-environment interactions, and the design of effective services to address associated risks. His research and applications focus on natural resources policy, development and decision-making in the Western U.S., Latin America, and the Caribbean.

Dr. Cynthia Rosenzweig, Senior Research Scientist at NASA Goddard Institute for Space Studies

Dr. Cynthia Rosenzweig served as a Coordinating Lead Author for Chapter 1 of the report entitled: *Assessment of Observed Chanced and Responses in Natural and Managed Systems.* Dr. Rosenzweig is a Senior Research Scientist at NASA Goddard Institute for Space Studies where she heads the Climate Impacts Group. She has organized and led large-scale interdisciplinary regional, national, and international studies of climate change impacts and adaptation. In addition, she serves as an Adjunct Professor in the Department of Environmental Science at Barnard. A recipient of a Guggenheim Fellowship, she has joined impact models with global and regional climate models to predict future outcomes of both land-based and urban systems under altered climate conditions.

Dr. Stephen H. Schneider, Co-Director of the Center for Environmental Science and Policy (CESP) and the Interdisciplinary Program in Environment and Resources (IPER) at Stanford University

Dr. Stephen H. Schneider served as a Coordinating Lead Author for Chapter 19: *Assessing Key Vulnerabilities and the Risk from Climate Change.* Currently, Dr. Schneider is a Professor in the Department of Biological Sciences and Co-Director of the Center for Environmental Science and Policy (CESP) and the Interdisciplinary Program in Environment and Resources (IPER) at Stanford University. His global change research interests include: climatic change; global warming; food/climate and other environmental/science public policy issues; ecological and economic implications of climatic change; integrated assessment of global change; climatic modeling of paleoclimates and of human impacts on climate, e.g., carbon dioxide "greenhouse effect" or environmental consequences of nuclear war. He is also interested in advancing public understanding of science and in improving formal environmental education in primary and secondary schools. Dr. Schneider received his Ph.D. in Mechanical Engineering and Plasma Physics from Columbia University in 1971.

Dr. Shardul Agrawala, Visiting Research Scholar in the Program in Science, Technology and Environmental Policy at Princeton University

Dr. Shardul Agrawala served as a coordinating lead author for Chapter 17 of the report: *Assessment of Adaptation Practices, Options, Constraints, and Capacity.* Dr. Agrawala is the Administrator for Climate Change, Environmental Directorate, Organization for Economic Co-operation and Development (OECD) in Paris, France. In addition, he is a Visiting Research Scholar with the Program in Science, Technology and Environmental Policy at the Woodrow Wilson School of Public and International Affairs, Princeton University. Dr. Agrawala received his Ph.D. from the Woodrow Wilson School of Public and International Affairs in 1999.

Chairman GORDON. Good morning. We have with us today six distinguished scientists who authored chapters of the second part of the Intergovernmental Panel on Climate Change Report that was released in Brussels on April 6. We know you have been on a whirlwind tour and we appreciate you coming and joining us today.

This second report moves beyond the fact that global warming is occurring to provide us with a picture of what global warming means for natural systems and human communities throughout the world. For the near-term, the picture is a mosaic of positive and negative impacts. Some areas are now experiencing changes that have put them at greater risk from drought, avalanches, floods and fires. For others, there are benefits in the form of lower heating costs, fewer deaths due to cold exposure, lengthening growing seasons and increases in crop yield.

Even our national security would be impacted by the effect of climate change. Recently the Pentagon released a study entitled "The National Security and the Threat of Climate Change" which looks at possible security problems including mass migrations, increased border tensions, greater demands for rescue and evacuation efforts, and conflicts over essential resources including food and water. In the long-term, negative impacts begin to overtake the positive impacts.

If we do not reduce emissions of greenhouse gases, our children and our grandchildren will face considerable challenges due to climate change in the latter half of this century. In the near-term, it appears we can implement strategies to cope with climate change impacts. We must start to adapt because the climate is changing and will continue to change even if we reduce emissions tomorrow. Adaptation will help our generation to cope with climate change. However, only mitigation will avoid and delay severe climate change impacts our children and grandchildren are projected to case.

I do not want to leave my daughter and her generation with the burden of a world with more food shortages, extended droughts, displaced coastal communities, increased public health problems and political instability created by increased numbers of people displaced by climate-driven changes in their environment.

The information brought to us in this report makes a compelling case for action. We need to make our communities more climate resistant. Adaptation is an essential near-term step to reduce vulnerability to climate change but adaptation alone is not enough. We owe it to our children and our future generations to lead the world in a global effort to reduce greenhouse gas emissions.

I thank our witnesses for appearing before us today and I also thank you for your service to the IPCC. I look forward to hearing your testimony.

[The prepared statement of Chairman Gordon follows:]

PREPARED STATEMENT OF CHAIRMAN BART GORDON

Good morning. Today we have six distinguished scientists who authored chapters of the second part of the Intergovernmental Panel on Climate Change's (IPCC) report that was released in Brussels on April 6.

This second report moves beyond the fact that global warming is occurring to provide us with a picture of what global warming means for natural systems and human communities throughout the world.

For the near-term, the picture is a mosaic of positive and negative impacts. Some areas are now experiencing changes that have put them at greater risk from drought, avalanches, floods, and fires.

For others there are benefits in the form of lower heating costs, fewer deaths due to cold exposure, lengthening growing seasons, and increases in crop yields.

Even our national security could be impacted by the effects of climate change. Just yesterday, the Center for Naval Analysis released a study entitled, *"National Security and the Threat of Climate Change,"* which looks at possible security problems including mass migrations, increased border tensions, greater demands for rescue and evacuation efforts, and conflicts over essential resources—including food and water.

In the long-term, negative impacts begin to overtake the positive impacts. If we do not reduce emissions of greenhouse gases our children and grandchildren will face considerable challenges due to climate change in the latter half of this century.

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The information brought to us in this report makes a compelling case for action.

We need to make our communities more climate resilient. Adaptation is an essential near-term step to reduce vulnerability to climate change.

But adaptation alone is not enough. We owe it to our children and all future generations to lead the world in a global effort to reduce greenhouse gas emissions.

I thank our witnesses for appearing before the Committee today. Thank you also for your service on the IPCC. I look forward to hearing your testimony.

Chairman GORDON. At this time I am pleased to yield to distinguished Ranking Member, Mr. Hall, for an opening statement.

Mr. HALL. Mr. Chairman, good morning. I am glad that our good Chairman organized this hearing about the important topic of climate change impacts, adaptation and vulnerability, and let me start by thanking all of the witnesses for being here today. Climate change is becoming a very key issue in the 110th Congress and we all appreciate your time and the scientific expertise that you can provide for our consideration.

Climate change is one of our nation's biggest challenges but so too are the equally important challenges of energy independence and affordability. Our nation needs solutions that address all of these issues and they need to be mutually exclusive goals. We can and should develop affordable energy solutions that reduce our carbon intensity while freeing our nation from the grip of foreign energy.

The scientific findings of this second IPCC working group will prompt much debate about what policies the United States should enact to address the potential impacts of climate change. The findings in the Working Group II's reports have even more uncertainty than those in the Working Group I report we heard about back in February. Some in Congress are proposing bills that would create a mandatory regulatory scheme to address carbon emissions. In considering these pieces of legislation, we must also, and always, weigh the cost and the benefits along with the unintended consequences that could result. The scientists at our hearing today can tell us their best analysis of what climate effects to expect at certain temperatures but they can't answer the policy issues posed above.

One issue that most of us agree on is that our country will experience impacts from climate change and we need to be ready to adapt to them. I have faith in American innovation and finding solutions to help us adapt to these changes. Last year I authored the *National Integrated Drought Information System Act* that authorized a program to improve drought forecasting and allow localities to better manage their water resources. Adaptation will be important, and I look forward to hearing from these experts as they explain their findings in this key area.

In the long run, the key to addressing climate change will be clean, affordable, and reliable energy technologies. We need much more discussion in Congress on how new technologies can help America become energy-independent and create a world with cleaner energy sources. There is a concentrated effort by a minority of the environmental community to declare war on energy and to declare war on growth in general, and a war on fossil fuels specifically. They need to realize that if China offers $1 a barrel of oil more than the U.S. now pays Saudi Arabia, we could overnight lose 60 percent of the energy we have from, guess what, fossil fuels. Let us not be ridiculous about our energy needs simply to give some politician or some editor a plaque for their walls.

I yield back my time.

[The prepared statement of Mr. Hall follows:]

PREPARED STATEMENT OF REPRESENTATIVE RALPH M. HALL

Good morning. I am glad the Chairman organized this hearing about the important topic of climate change impacts, adaptation and vulnerability. Let me start by thanking all of the witnesses for being here today. Climate change is becoming a key issue in the 110th Congress and we all appreciate your time and the scientific expertise that you can provide to inform our policy discussions.

Climate change is one of our nation's biggest challenges, but so too are the equally important challenges of energy independence and affordability. Our nation needs solutions that address all of these issues, and they need not be mutually exclusive goals. We can, and should, develop affordable energy solutions that reduce our carbon intensity while freeing our nation from the grip of foreign energy.

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One issue that most of us agree on is that our country will experience impacts from climate change and we need to be ready to adapt to them. I have faith in American innovation in finding solutions to help us adapt to theses changes. Last year, I authored the *National Integrated Drought Information System Act* that authorized a program to improve drought forecasting and allow localities to better manage their water resources. Adaptation will be important and I look forward to hearing from these experts today as they explain their findings in this key area.

In the long run, the key to addressing climate change will be clean, affordable, and reliable energy technologies. We need much more discussion in Congress on how new technologies can help America become energy independent and create a world with cleaner energy sources.

I look forward to hearing from our witnesses today and yield back the balance of my time.

Chairman GORDON. Thank you, Mr. Hall, and I think there are lots of areas within your statement that we have consensus on and I look forward to working with you.

If there are Members who wish to submit additional opening statements, your statements will be added to the record.

[The prepared statement of Mr. Costello follows:]

PREPARED STATEMENT OF REPRESENTATIVE JERRY F. COSTELLO

Good morning. I want to thank Chairman Gordon for holding today's hearing on the second section of the 2007 Fourth Assessment Report, *Climate Change 2007: Climate Change Impacts, Adaptation and Vulnerability,* prepared by Working Group II of the Intergovernmental Panel on Climate Change (IPCC). The report examines the current state of scientific knowledge on the impacts of climate change on natural and human systems around the world. A large amount of progress has been made in understanding and projecting the effects of future climate change since the previous IPCC report.

This report gives the Congress added information on global warming, and as we begin to craft legislation. This process needs to be one of consensus, taking a wide view of our current energy realities as well as the goals we need to reach in the future. Toward this end, we cannot ignore the reality that coal is going to play a role in our nation's energy supply and the world energy supply for years to come. Coal generates half of the electricity in this country and is a reliable domestic source of power with a 250-year supply of coal in the U.S. alone. To fully maximize our use of coal, we must continue to take steps that reduce emissions. The only way to achieve this goal is through advancements in technology. I have been a strong supporter of clean coal initiatives and programs to advance the research and development needed to improve coal-based electricity generation. Congress must continue to support the clean coal programs in the President's FY08 budget, which includes the FutureGen Project, slated to be the world's first zero-emissions coal plant. Among other things, FutureGen will demonstrate the ability to sequester carbon dioxide emissions safely underground. The more coal plants using clean coal technology equals reduced greenhouse gas emissions.

Clean coal technologies do exist; however, they need the support and backing from Congress to further develop and demonstrate their commercial viability. As we consider climate change legislation, I encourage my colleagues to include coal as part of our energy solution. Again, I look forward to working with my colleagues as we find practical solutions that lead us down the path of energy independence and protection of our environment.

I welcome the panel of witnesses and look forward to their testimony.

[The prepared statement of Mr. Lampson follows:]

PREPARED STATEMENT OF REPRESENTATIVE NICK LAMPSON

Good morning. Thank you Chairman Gordon for holding a hearing on this important report on the current and future impacts of climate change.

For some time now we have gambled with the future of our children and grandchildren. We have acted as if the early projections of climate change offered by the scientific community were very unlikely—as if global warming was not occurring, or that our actions had no effect on Earth's climate system.

Over the past decade, however, the scientific evidence and consensus on climate change has grown stronger. The new IPCC report and the one released earlier this year make it clear that if we continue to avoid addressing global warming, future generations will bear the burden of these negative climate change consequences.

This report is a call to action. We must identify key risks and vulnerabilities for both human and natural systems. We must develop and implement adaptation strategies to reduce the identified risks and vulnerabilities. To buy more time and secure a better future, we must develop and implement mitigation strategies to bring greenhouse gas emissions under control. It is the only way to avoid the severe negative impacts projected to occur later this century.

In my home State of Texas we are too well-acquainted with the devastating effects of severe weather events on individuals, communities, and the economy. Extended droughts, tornadoes, and hurricanes are devastating for families who experience them and extremely expensive for the Federal, State, and local governments that must respond to and cope with them. If we succeed in reducing our vulnerability to these events, we will not only reduce the monetary costs of confronting these events, we will also avoid the human stress, suffering, and loss associated with them.

I realize some changes we must make will be difficult. This effort will require significant investment and sacrifices on all our parts. But it is better to undertake changes and direct them with foresight and planning than to have them forced upon us in crisis situations. Let's get to work on securing safe, climate-resilient communities here at home and abroad.

I want to thank all our witnesses for appearing before the Committee this morning and for contributing their time and talents to producing this important report.

[The prepared statement of Mr. Mitchell follows:]

PREPARED STATEMENT OF REPRESENTATIVE HARRY E. MITCHELL

Thank you, Mr. Chairman.

In February, we heard from some of the world's top scientists about the growing threat of global warming who reported to this committee some of the important findings of the International Panel on Climate Change (IPCC).

I think many of us were concerned about what they had to say, and troubled by the scientific data that demonstrates the threat of global warming and climate change isn't simply a threat—it's happening all across the world.

The findings of the IPCC Working Group II further demonstrate that climate change's footprint is clearly everywhere.

Water allocation is a pressing issue for Arizona and, according to the working group's most recent report, it will only get worse.

According to a recent article in the *Seattle Times,* scientists analyzing Working Group II's data found that the driest periods of the last century such as the Dust Bowl of the 1930's could become the norm for Southwest U.S. within decades. The greatest effects will be felt along the U.S.-Mexico border and, climate researchers predict, by 2100, rainfall will decline by 10 to 20 percent annually.

I look forward to learning more about Working Group II's findings today. Understanding the regional affects and human vulnerabilities to the coming changes in climate are essential to adequately adapt to and diminish the effects of this change.

I yield back the balance of my time.

[The prepared statement of Mr. Ehlers follows:]

PREPARED STATEMENT OF REPRESENTATIVE VERNON J. EHLERS

I am pleased that the Science and Technology Committee is hearing from scientists who participated in the second Working Group of the Intergovernmental Panel on Climate Change (IPCC). I understand that preparing this report is an exhaustive, very diplomatic process and I commend these scientists for their willingness to work in arenas that may not be as comfortable as their home institutions. Both our country, and the rest of the world, benefit from your sustained commitment to sharing quality scientific information.

It is disheartening to read this report and understand that even immediate actions to curb greenhouse gas emissions will not be able to stop near-term impacts of climate change. We are past the point of acknowledging that this is a real issue and have moved forward to the discussion of adaptation strategies. Based on this most recent report, it is clear that some regions of the globe will benefit from global warming. In fact, U.S. agriculture may actually see an increased growing season and consequent productivity. But at some point even regions that initially benefit will also succumb to secondary effects such as water shortages. As part of curing our climate problem, we must recognize that those who benefit in the short-term from warming trends may have less motivation to take actions to reduce greenhouse gas emissions. Yet we must have an allied effort of both science and diplomacy working hand-in-hand to achieve significant reductions.

In order to address climate change we must identify the problem, determine the causes, and propose and adopt appropriate solutions. We recently heard from Working Group I of the IPCC, which concluded with high certainty that scientific research shows we have a problem, and that humans are one major cause behind the problem. Working Group II addressed the impacts of climate change and will help us make initial steps to adapt to changes in our environment. While adapting to the changes is pragmatic, it is not a comprehensive solution.

I realize that today we are only concentrating on one facet of a most complicated problem. The additional working groups of the IPCC also will help address the broader policy questions of climate change strategy, and I look forward to reviewing those results as well.

I thank the witnesses for being here today, and look forward to the opportunity to hear what they have to say.

Chairman GORDON. At this time I would like to introduce our witnesses. First, Dr. Cynthia Rosenzweig was the Coordinating Lead Author of Chapter 1, *Assessment of Observed Changes and Responses in the Natural and Managed Systems of the Working Group II Reports on Impacts, Adaptation and Vulnerably*. Currently, Dr. Rosenzweig is a senior research scientist at NASA Goddard Institute for Space Studies, where she heads up the Climate Impact Group. Welcome.

Our next witness will be Dr. William Easterling, who served as Coordinating Lead Author for Chapter 5, *Food, Fibre and Forest Products*. Dr. Easterling is the Director of Pennsylvania State University Institutes of the Environment and as of July 1 will become Dean of the College of Earth and Mineral Sciences at Penn State.

Dr. Roger Pulwarty was the Lead Author of Chapter 17, *Assessment of Adaptation Practices, Opinions and Constraints and Capacity*. Currently, Dr. Pulwarty is a physical scientist at the NOAA Climate Diagnostic Center in Boulder, Colorado. And Dr. Stephen Schneider is Professor of Interdisciplinary Environmental Studies, Biological Sciences and Civil Environmental Engineering and Co-Director of the Center for Environmental Science and Policy and Interdisciplinary Program and Environment and Resources at Stanford University. Dr. Schneider served as the Coordinating Lead Author for Chapter 19, *Assessing Key Vulnerabilities and the Risk from Climate Change*.

And I know Mr. Melancon would like to be here, I think he is on his way, because he has a constituent in Dr. Virginia Burkett, who is the Lead Author of Chapter 6, *Coastal Systems and Low-Lying Areas,* and USGS global change science coordinator at the National Wetlands Research Center. So when Mr. Melancon comes here, we will say nice things about you, Dr. Burkett.

We do thank you for coming. You have been on a whirlwind. I know this has been a very tough few years getting ready for this. I know some of our previous authors in Working Group I said it was the most really physically, intellectually demanding thing they have been through and so we appreciate your work and we welcome you here.

Well, Mr. Hall had to take testimony at another hearing and we are glad that Dr. Ehlers is here for introduction of the final witness. Okay, he is not. Well, let us see. Does the Minority have a witness here? Yes. I am going to let you help me. Do you want to go forward?

Mr. EHLERS. Sorry about the confusion but Mr. Hall had to leave for an urgent meeting. I am very pleased to introduce Mr. Shardul Agrawala. Thank you very much for participating here in this particular event, and I might add that I admire all of you for your willingness to depart the comfort of your individual offices scattered around the country and to participate in this exhausting and exhaustive work that you have done, and I deeply appreciate it.

With that, I will return it to the Chairman.

Chairman GORDON. Thank you, Dr. Ehlers.

The previous Chairman, Sherwood Boehlert, used to say that although witnesses are supposed to complete their testimony in five minutes, that 300 seconds on a very important issue like we have today is a little bit confining. So we have your regular testimony so we hope you will summarize but we don't want you to feel under great constraints when the red button comes, but we would like to get home tonight.

Dr. Rosenzweig, we will yield to you.

STATEMENT OF DR. CYNTHIA ROSENZWEIG, SENIOR RESEARCH SCIENTIST, NASA GODDARD INSTITUTE FOR SPACE STUDIES, THE EARTH INSTITUTE AT COLUMBIA UNIVERSITY

Dr. ROSENZWEIG. Thank you, Mr. Chairman. My testimony comes from Section B of the Working Group II contribution to the Intergovernmental Panel on Climate Change, which is called the *Climate Change 2007 Climate Change Impacts, Adaptation and Vulnerability*. This is from the approved summary for policy-makers.

This part of the summary concerns the relationship between observed climate changes and recent observed changes in natural and human environments. The statements presented here are based largely on data sets that cover the period since 1970. The number of studies of observed trends in the physical and biological environment and their relationship to regional climate changes has increased greatly since the Third Assessment in 2001. The map shows the temperature rises since 1970 and the data series of changes in physical and biological systems that were assessed in the chapter.

From the current assessment, we conclude that observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases. With regard to changes in snow, ice and frozen ground including permafrost, examples are enlargement and increased numbers of glacial lakes, increasing ground instability in permafrost regions and rock avalanches in mountain regions. There are also changes in some Arctic and Antarctic ecosystems including those in sea ice biomes and also predators high in the food chain; among them, polar bears.

The following types of hydrological systems are being affected around the world: increased runoff and earlier spring peak discharge in many glacier and snow-fed rivers and warming of lakes and rivers in many regions with effects on thermal structure and water quality. Recent warming is also strongly affecting terrestrial biological systems such as earlier timing of spring events. Examples are leaf unfolding and blooming, bird migration and egg laying, and pole-ward and upward shifts in ranges in plant and animal species.

There is also substantial new evidence about observed changes in marine and freshwater biological systems. These include shifts in ranges and changes in algal, plankton and fish abundance in high-latitude oceans, increases in algal and zooplankton abundance in high-latitude and high-altitude lakes, range changes and earlier migrations of fish in rivers.

The changes I just described were responding at the regional scale. In Chapter 1, what we also did was do a global assessment looking at all of the changes, assessing all the changes together. Here we find that a global assessment of data since 1970 has shown it is likely that anthropogenic warming has had a discernible influence on many physical and biological systems. There are four sets of evidence which taken together support this conclusion. The first is coming from our colleagues in Working Group I, who concluded that most of the observed increase in the globally average temperature since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations.

The second line of evidence is of the more than 29,000 observational data series, there are dots representing 29,000 data series from 75 studies that show significant change in many physical and biological systems. More than 89 percent are consistent with a direction of change exhibited as a response of warming.

The third line of evidence is that of a global synthesis of studies in this assessment strongly demonstrates that the spatial agreement between the regions of significant warming across the globe and the locations of the significant observed changes in the natural systems consistent with warming is very unlikely to be due solely to natural variability of the temperatures nor of the systems themselves.

Finally, there have been several modeling studies that have linked responses in some physical and biological systems to anthropogenic warming.

Consistency between the observed and model changes in several studies and the spatial agreement between significant regional warming and consistent impacts at the global scale is sufficient to conclude with high confidence that anthropogenic warming over the last three decades has had a discernible influence on many physical and biological systems.

Thank you, Mr. Chairman.

[The prepared statement of Dr. Rosenzweig follows:]

PREPARED STATEMENT OF CYNTHIA ROSENZWEIG

Dr. Cynthia Rosenzweig is entering into testimony Section B of the Working Group II Contribution to the Intergovernmental Panel on Climate Change, *Climate Change 2007: Climate Change Impacts, Adaptation and Vulnerability Approved Summary for Policy-makers.*

Current knowledge about observed impacts of climate change on the natural and human environment

A full consideration of observed climate change is provided in the IPCC Working Group I Fourth Assessment. This part of the Summary concerns the relationship between observed climate change and recent observed changes in the natural and human environment.

The statements presented here are based largely on data sets that cover the period since 1970. The number of studies of observed trends in the physical and biological environment and their relationship to regional climate changes has increased greatly since the Third Assessment in 2001. The quality of the data sets has also improved. There is, however, a notable lack of geographic balance in data and literature on observed changes, with marked scarcity in developing countries.

These studies have allowed a broader and more confident assessment of the relationship between observed warming and impacts than was made in the Third Assessment. That Assessment concluded that "there is high confidence[1] that recent regional changes in temperature have had discernible impacts on many physical and biological systems."

From the current Assessment we conclude the following.

[1] See Endbox 2.

Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases.

With regard to changes in snow, ice and frozen ground (including permafrost)[2], there is high confidence that natural systems are affected. Examples are:

- enlargement and increased numbers of glacial lakes [1.3];
- increasing ground instability in permafrost regions, and rock avalanches in mountain regions [1.3];
- changes in some Arctic and Antarctic ecosystems, including those in sea-ice biomes, and also predators high in the food chain [1.3, 4.4, 15.4].

Based on growing evidence, there is high confidence that the following types of hydrological systems are being affected around the world:

- increased run-off and earlier spring peak discharge in many glacier- and snow-fed rivers [1.3];
- warming of lakes and rivers in many regions, with effects on thermal structure and water quality [1.3].

There is very high confidence, based on more evidence from a wider range of species, that recent warming is strongly affecting terrestrial biological systems, including such changes as:

- earlier timing of spring events, such as leaf-unfolding, bird migration and egg-laying [1.3];
- poleward and upward shifts in ranges in plant and animal species [1.3, 8.2, 14.2].

Based on satellite observations since the early 1980s, there is high confidence that there has been a trend in many regions towards earlier 'greening'[3] of vegetation in the spring linked to longer thermal growing seasons due to recent warming. [1.3, 14.2]

There is high confidence, based on substantial new evidence, that observed changes in marine and freshwater biological systems are associated with rising water temperatures, as well as related changes in ice cover, salinity, oxygen levels and circulation [1.3]. These include:

- shifts in ranges and changes in algal, plankton and fish abundance in high-latitude oceans [1.3];
- increases in algal and zooplankton abundance in high-latitude and high-altitude lakes [1.3];
- range changes and earlier migrations of fish in rivers [1.3].

The uptake of anthropogenic carbon since 1750 has led to the ocean becoming more acidic with an average decrease in pH of 0.1 units [IPCC Working Group I Fourth Assessment]. However, the effects of observed ocean acidification on the marine biosphere are as yet undocumented. [1.3]

A global assessment of data since 1970 has shown it is likely[4] that anthropogenic warming has had a discernible influence on many physical and biological systems.

Much more evidence has accumulated over the past five years to indicate that changes in many physical and biological systems are linked to anthropogenic warming. There are four sets of evidence which, taken together, support this conclusion:

1. The Working Group I Fourth Assessment concluded that most of the observed increase in the globally averaged temperature since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations.
2. Of the more than 29,000 observational data series[5], from 75 studies, that show significant change in many physical and biological systems, more than

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[2] See IPCC Working Group I Fourth Assessment Report Summary for Policy-makers.

[3] Measured by the Normalised Difference Vegetation Index, which is a relative measure of the amount of green vegetation in an area based on satellite images.

[4] See Endbox 2.

[5] A subset of about 29,000 data series was selected from about 80,000 data series from 577 studies. These met the following criteria: (1) Ending in 1990 or later; (2) spanning a period of

Continued

89 percent are consistent with the direction of change expected as a response to warming. (Figure SPM–1) [1.4]

3. A global synthesis of studies in this Assessment strongly demonstrates that the spatial agreement between regions of significant warming across the globe and the locations of significant observed changes in many systems consistent with warming is very unlikely to be due solely to natural variability of temperatures or natural variability of the systems. (see Figure SPM–1) [1.4]
4. Finally, there have been several modelling studies that have linked responses in some physical and biological systems to anthropogenic warming by comparing observed responses in these systems with modelled responses in which the natural forcings (solar activity and volcanoes) and anthropogenic forcings (greenhouse gases and aerosols) are explicitly separated. Models with combined natural and anthropogenic forcings simulate observed responses significantly better than models with natural forcing only. [1.4]

Limitations and gaps prevent more complete attribution of the causes of observed system responses to anthropogenic warming. First, the available analyses are limited in the number of systems and locations considered. Second, natural temperature variability is larger at the regional than the global scale, thus affecting identification of changes due to external forcing. Finally, at the regional scale other factors (such as land-use change, pollution, and invasive species) are influential. [1.4]

Nevertheless, the consistency between observed and modelled changes in several studies and the spatial agreement between significant regional warming and consistent impacts at the global scale is sufficient to conclude with high confidence that anthropogenic warming over the last three decades has had a discernible influence on many physical and biological systems. [1.4]

Other effects of regional climate changes on natural and human environments are emerging, although many are difficult to discern due to adaptation and non-climatic drivers.

Effects of temperature increases have been documented in the following systems (medium confidence):

- effects on agricultural and forestry management at Northern Hemisphere higher latitudes, such as earlier spring planting of crops, and alterations in disturbance regimes of forests due to fires and pests [1.3];
- some aspects of human health, such as heat-related mortality in Europe, infectious disease vectors in some areas, and allergenic pollen in Northern Hemisphere high and mid-latitudes [1.3, 8.2, 8.ES];
- some human activities in the Arctic (e.g., hunting and travel over snow and ice) and in lower elevation alpine areas (such as mountain sports). [1.3]

Recent climate changes and climate variations are beginning to have effects on many other natural and human systems. However, based on the published literature, the impacts have not yet become established trends. Examples include:

- Settlements in mountain regions are at enhanced risk to glacier lake outburst floods caused by melting glaciers. Governmental institutions in some places have begun to respond by building dams and drainage works. [1.3]
- In the Sahelian region of Africa, warmer and drier conditions have led to a reduced length of growing season with detrimental effects on crops. In southern Africa, longer dry seasons and more uncertain rainfall are prompting adaptation measures. [1.3]
- Sea-level rise and human development are together contributing to losses of coastal wetlands and mangroves and increasing damage from coastal flooding in many areas. [1.3]

at least 20 years; and (3) showing a significant change in either direction, as assessed in individual studies.

Changes in physical and biological systems and surface temperature 1970-2004

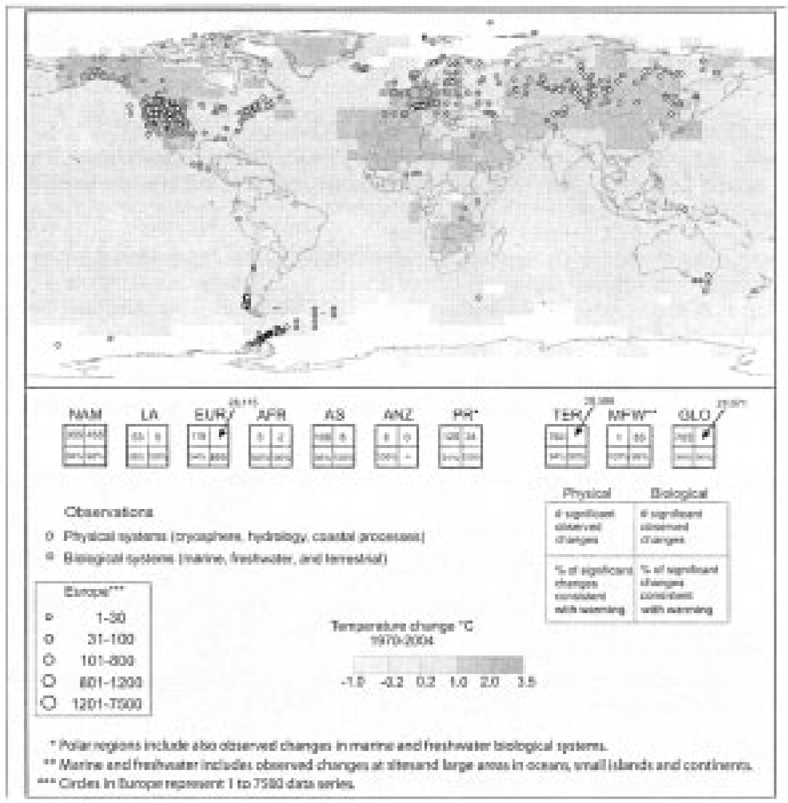


Figure SPM–1. Locations of significant changes in observations of physical systems (snow, ice and frozen ground; hydrology; and coastal processes) and biological systems (terrestrial, marine, and freshwater biological systems), are shown together with surface air temperature changes over the period 1970–2004. A subset of about 29,000 data series was selected from about 80,000 data series from 577 studies. These met the following criteria: (1) Ending in 1990 or later; (2) spanning a period of at least 20 years; and (3) showing a significant change in either direction, as assessed in individual studies. These data series are from about 75 studies (of which ?70 are new since the Third Assessment) and contain about 29,000 data series, of which about 28,000 are from European studies. White areas do not contain sufficient observational climate data to estimate a temperature trend. The 2 x 2 boxes show the total number of data series with significant changes (top row) and the percentage of those consistent with warming (bottom row) for (i) continental regions:

North America (NAM), Latin America (LA), Europe (EUR), Africa (AFR), Asia (AS), Australia and New Zealand (ANZ), and Polar Regions (PR) and (ii) global-scale: Terrestrial (TER), Marine and Freshwater (MFW), and Global (GLO). The numbers of studies from the seven regional boxes (NAM, . . ., PR) do not add up to the global (GLO) totals because numbers from regions except Polar do not include the numbers related to Marine and Freshwater (MFR) systems. [F1.8, F1.9; Working Group I Fourth Assessment F3.9b]

Endbox 2. Likelihood and confidence language

In this Summary for Policymakers, the following terms have been used to indicate the assessed likelihood of an outcome or a result:
Virtually certain > 99% probability of occurrence, *Extremely likely* > 95%, *Very likely* > 90%, *Likely* > 66%, *More likely than not* > 50%, *Very unlikely* < 10%, *Extremely unlikely* < 5%.

The following terms have been used to express confidence in a statement:
Very high confidence At least a 9 out of 10 chance of being correct, *High confidence* About an 8 out of 10 chance, *Medium confidence* About a 5 out of 10 chance, *Low confidence* About a 2 out of 10 chance, *Very low confidence* Less than a 1 out of 10 chance.

BIOGRAPHY FOR CYNTHIA ROSENZWEIG

Dr. Cynthia Rosenzweig is a Senior Research Scientist at the NASA Goddard Institute for Space Studies located at Columbia University. Her primary research involves the development of interdisciplinary methodologies by which to assess the potential impacts of and adaptations to global environmental change. Recognizing that the complex interactions engendered by global environmental change can best be understood by coordinated teams of experts, Dr. Rosenzweig has organized and led large-scale interdisciplinary, national, and international studies of climate change impacts and adaptation. She co-led the Metropolitan East Coast Regional Assessment of the U.S. National Assessment of the Potential Consequences of Climate Variability and Change, sponsored by the U.S. Global Change Research Program. She is a recipient of the Guggenheim Fellowship and is a Fellow of both the American Association for the Advancement of Science and the American Society of Agronomy. She leads the Climate Impacts Research Group at the Goddard Institute of Space Studies, whose mission is to investigate the interactions of climate variability and change on systems and sectors important to human well-being. For the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC), she is the Co-Coordinating Lead Author for Chapter One, *Assessment of Observed Changes and Responses in Natural and Managed Systems,* of Working Group II on Impacts, Adaptation, and Vulnerability.

Chairman GORDON. Thank you, Dr. Rosenzweig.

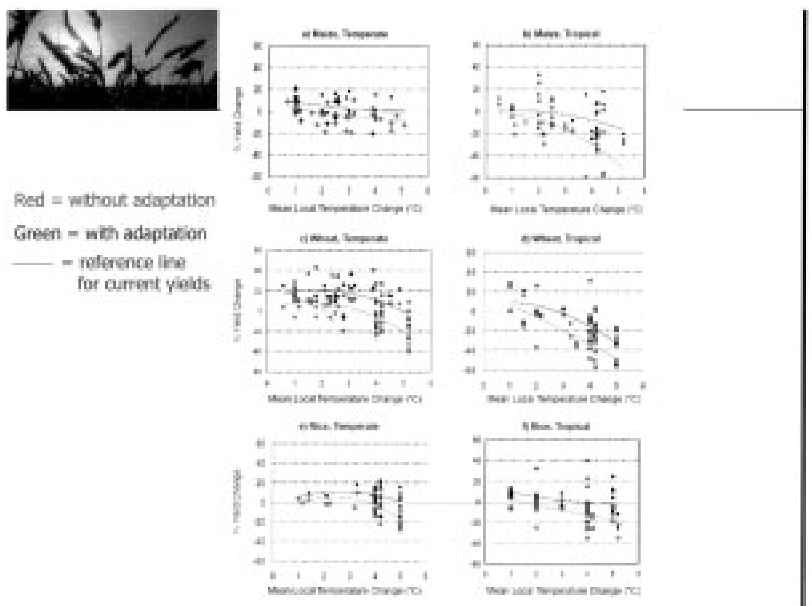
And now, Dr. William Easterling is recognized for five minutes.

STATEMENT OF DR. WILLIAM E. EASTERLING, PROFESSOR OF GEOGRAPHY AND AGRONOMY; DIRECTOR, PENN STATE INSTITUTES OF ENERGY AND THE ENVIRONMENT, PENNSYLVANIA STATE UNIVERSITY

Dr. EASTERLING. Good morning, Chairman Gordon and distinguished Members of the Committee and ladies and gentlemen, I am Bill Easterling, and since I was introduced, I will dispense with a lot of background information and just get straight to the point.

I think that one of the great human achievements of the 20th century was the progress that the world's farmers made in increasing global food production in step with the increase in demand for food. Even though hunger certainly persists everywhere in the world, there is no question that the farmers have been successful in generating the calories that we need to feed the plant, and the question before us, and this was one of the central questions we asked in the IPCC report on food and fibre and forestry was, can this continue in the future under climate change.

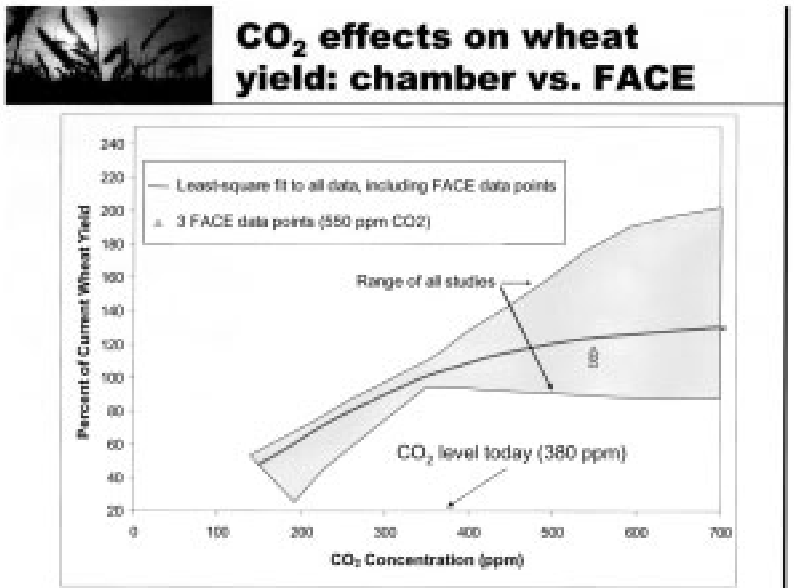
Let me begin by saying that a large amount of progress has been made since the last IPCC report in understanding and projecting the effects of future climate change on agricultural production, although to be sure, significant uncertainties remain. It can now be stated with higher confidence than before that climate change is likely to challenge food security among the world's poorest people, particularly in countries in the low latitudes, in the tropics. Most of the crops are grown there under conditions that are near the top of those crops' optimal temperature range and any warming at all pushes them over the top and yields begin to fall.



Now, my first slide although it is difficult to see I know from where you are but it is a snapshot and I will walk you through it, tells the story with a series of graphs that show the synthesis of nearly 70 recent modeling studies that have been divided between the temperature mid to high latitudes and the tropical low latitudes. On these graphs, the cereal crop maize or, as we know it, corn, wheat and rice yields which those by the way three cereals make up about 75 to 80 percent of the total calories either consumed by us as humans or by livestock as feed, are shown as percentages of current yields versus increasing mean temperature. We thought to be an effective way of summarizing what we have learned about the effects of warming on crop yields. Many of these studies were performed with and without adaptation assumptions and the adaptations might be changes in planting times and cultivar selections, commonsensical adaptations that farmers would probably engage on their own. The red dots and lines are results without adaptation and the green dots and lines are with adaptation, so notice that the red lines for the tropics show yields in all three crops dropping below current levels after little more than one degree Celsius of warming.

Now, the warming will be less troublesome, according to our analysis, to agricultural systems in the mid to high latitudes like the U.S., at least in the early stages of the warming, and notice the red lines for the temperate mid- to high-latitude crops remain above the current yields for the first few degrees of warming before they begin to tail off. The green lines indicate that adaptation effectively keeps the temperate cereal crops near or above current yields through moderate amounts of warming, say about four to five degrees Celsius of warming, but it only protects low-latitude tropical crops for a few degrees, maybe about three degrees of warming. All of the studies in these graphs include the beneficial effect of rising atmospheric CO_2, or carbon dioxide, levels on crop growth. This is the so-called CO_2 fertilization effect. There has been recent controversy over the strength of the CO_2 fertilization effect with some scientists feeling that we have tended to overestimate the strength. This would imply that our global estimates of climate change damages to food production from previous studies are too low. Their arguments, scientists who are questioning the CO_2 effect, are based on the most recent and realistic field experiments to date.

The second slide gives you a visual snapshot of the old and new experimental approaches and the old approach is the chamber experimental approach that is on the left side. It is not—it is a very artificial environment versus the newer free-air carbon enrichment rings out in fields where the CO_2 is actually applied in measured ways to simulate a much more realistic environment. Our assessment, after careful comparison of the older experimental results with the new ones, is that the effects are not enough different to warrant concern.



Our third slide shows how we reached this conclusion. It shows wheat yields as percentages of current yields versus different levels of atmospheric CO_2 for both the old and the new experiments. While there are too many experiment data points to plot them all, it would make this look like a bowl of spaghetti, these data points are fully contained within the blue shaded range on the graph. The red line describes the general trend of the old experiments and the three data points for the new experiments are plotted as red triangles at 550 parts per million CO_2. Looking at it this way shows that the new results are well within the range of the old results, and the green oval on the graph brings it to your attention. Hence, our conclusion is that the existing estimates of CO_2 effects on food supply under climate change would appear to be valid.

My final point, and Mr. Chairman, I can summarize this in just a matter of a minute or two, is that a growing preponderance of studies show that if the climate changes are accompanied by increasing climate variability, droughts and floods and extreme events like those, crop yield losses are likely to occur at even smaller mean temperature increases than if variability is unchanged. So the numbers I showed you before might look a bit different if variability changes appreciably from our current experience. For example, one study computed that under scenarios of increased heavy precipitation, production losses due to excessive soil moisture would double in the U.S. by 2030.

Those are among the more important findings of our chapter, and I thank you for your attention and would be happy to answer questions at the appropriate time.

[The prepared statement of Dr. Easterling follows:]

PREPARED STATEMENT OF WILLIAM E. EASTERLING[1]

Introduction

My name is Bill Easterling. I am Professor of Geography and Agronomy at Penn State University and Director of the Penn State Institutes of Energy and the Environment. I have authored over 70 refereed scientific publications in the areas of food and climate, which are cited extensively, and I have given hundreds of presentations concerning my areas of expertise. My research interests focus especially on the simulation of agricultural adaptation to climate change. I have been a member of many national and international committees, including chairing the National Research Council's Panel on the Human Dimensions of Seasonal-to-Inter-annual Climate Variability. I have contributed to the efforts of the Intergovernmental Panel on Climate Change (IPCC) in several ways, and serve as a Convening Lead Author on Chapter 5 (*Food, Fibre, Forestry, and Fisheries*), and on the Technical Summary and the Summary for Policy-makers of Working Group II of the Fourth Assessment Report.

The Food and Climate Challenge

The global expansion of the world's food supply in lock-step with growing world food demand is one of humanity's great achievements of the 20th and first years of the 21st centuries. Hunger surely persists in nearly every country today, but not because of shortage in the world's supply of food calories. By the latter third of this century, the world's farmers will be challenged to feed as many as 10–12 billion people who are likely to be, in the main, wealthier and more demanding in their food tastes than today. There are reasons to be optimistic that this challenge can be met in a future world that co-evolves with a stable climate, although emerging issues such as rising demand for bioenergy from crops could greatly increase pressures on food production. This overall challenge and any additional pressures will, in the long-run, be exacerbated by climate change.

As my colleague, Dr. Cynthia Rosenzweig notes in her testimony, the effects of recent climate variability and change on agriculture are being observed now in the form of longer growing seasons and faster temperature-regulated plant growth, especially in North America and Europe. As climate change intensifies in the future, so are those and many other agricultural effects expected to intensify. The newly released IPCC Working Group II report reaffirms a growing consensus among literally hundreds of field-based experiments and model-based simulation studies that rising atmospheric carbon dioxide concentration, hereafter [CO_2], and climate change will provide temporary benefits in some regions and for some crops and immediate loss in other regions and crops. In particular, our chapter documents regional trends that point to major crop yield loss in the low latitudes, where a majority of the poorest people in the world live, and temporary crop yield gains in the mid- to high latitudes.

I wish to speak to three major sets of findings concerning the potential consequences of future climate change for agricultural production at world and regional levels. They are: 1) the distribution of possible crop yield winners and losers across the Earth and the potential of adaptation to mediate that distribution; 2) the potential for rising [CO_2] to offset climate change-induced crop yield loss (or enhance yield gains); and 3) the effects of change in climate variability versus slow, steady climate change on crops. In addressing those points, I will rely on the recent IPCC Working Group II report exclusively.

Large regional variation in climate change effects on cereal crop productivity

Yield projections for the cereals maize (corn), wheat, and rice from nearly 70 studies that used physiologically-based plant simulation models are shown in Figure 1 below. The yield projections are expressed as percentage changes due to climate change with respect to current observed mean yields. Results are divided into "without adaptation" and "with adaptation" cases as discussed below. In the "without adaptation" case, model experiments were performed with the assumption that farmers take no action to respond to climate change. Without adaptation, the models broadly agree that, in mid- to high latitude regions (including North America), moderate to medium local increases in mean annual temperature (+1–3 C), along with associated [CO_2] increase and precipitation changes, can have small beneficial impacts on crop yields (see Figure 1 below). Those increases are the result of longer

[1] Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author and do not necessarily reflect those of The Pennsylvania State University, the Intergovernmental Panel on Climate Change, or other organizations.

growing seasons together with generally rising precipitation across many major grain belts.

Similar projections in low latitudes (tropics and parts of subtropics) indicate falling cereal yields with even moderate annual temperature increase (+1–2 C) and associated [CO_2] increase. Cereal crops in low latitudes are currently grown at temperatures near the peak of their optimum photosynthetic range; any warming at all pushes crops past the edge of that range into sub-optimal photosynthetic temperatures, hence yield loss.

Mean global temperature increases beyond approximately +3 C result in a downturn of cereal yields in the mid- to high latitudes, with some exceptions (e.g., northern North America, northern Europe). This yield decrease occurs because of higher heat stress combined with increased evapotranspiration that begins to dry soils in spite of higher precipitation. Further warming has increasingly negative impacts on cereal yields globally. Decreasing yields globally eventually are expected to slow growth in agricultural production relative to growth in agricultural demand.

In the "with adaptation" case, model experiments in these same 70 studies were performed with the assumption that farmers take action by changing planting dates in order to accommodate earlier spring warm-up and cultivar selection for the longer growing seasons under climate change. The "with adaptation" results indicate that some of the yield loss reported above can be offset, again, depending on location. In the mid- to high latitudes, as shown in Figure 1, adaptation allows cereal yields to be maintained at or above current levels beyond ~+5 C, but only up to ~+3 C in the low latitudes, depending on the crop. Beyond ~+3 C in the low latitudes, adaptation is no longer effective for cereals.

Potential for rising [CO_2] to offset climate change-induced crop yield loss (or enhance yield gains)

Higher [CO_2] levels increase photosynthesis and water use efficiency in most plants, with certain crops (C_3 species such as wheat, rice, soybeans) showing greater response than other crops (C_4 species such as corn, sorghum). Recent experimental studies based on realistic field conditions indicate that, at 550 ppm CO_2 (CO_2 levels are currently at approximately 380 ppm) yields increase under unstressed conditions by 10–25 percent for C_3 crops, and by 0–10 percent for C_4 crops, consistent with previous IPCC estimates. Based on these recent studies, some researchers have argued that crop response to elevated CO_2 may be lower than previously thought, with consequences for crop model projections of yields and food supply. The basis for their argument is that the [CO_2] effects in current crop models are derived from earlier, less realistic experiments that tended to exhibit higher [CO_2] sensitivity of the crops than the recent studies. However, other researchers have carefully compared the results of the two experimental approaches and find that these new experimental findings are in fact consistent with previous. In addition, simulations of unstressed plant growth and yield response to elevated CO_2 in the main crop simulation models have been shown to be in line with recent experimental data, projecting crop yield increases of about 5–20 percent at 550 ppm CO_2. These findings reaffirm the validity of earlier projections of crop productivity and food production. It is worth pointing out, however, that current crop models do not have adequate internal structures for representing the effects of pests, disease, and certain extreme weather events (hail, hurricanes and other flooding), all of which lower the confidence in their projections.

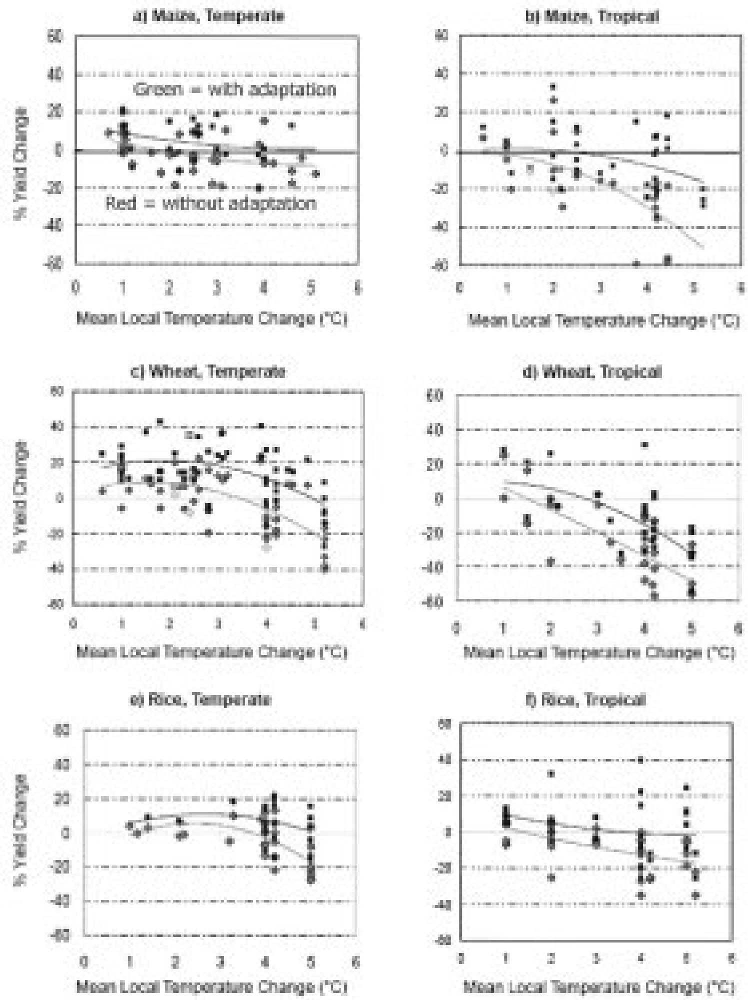
A change in climate variability is worse for crops than slow, gradual climate change

Climate change is most likely to become evident to farmers not by gradual change in climate conditions, but rather by changes in the frequencies of damaging extremes such as droughts, excessive rainfall, and heat stress. Recent studies indicate that climate changes that include increased frequency of heat stress and droughts reduce crop yields and livestock productivity beyond the impacts due to changes in mean variables alone, creating the possibility for surprises. A number of simulation studies performed since the previous IPCC report have examined specific aspects of increased climate variability within climate change scenarios. For example, one study computed that, under scenarios of increased heavy precipitation, production losses due to excessive soil moisture would double in the U.S. by 2030. More frequent extreme events may lower long-term yields by directly damaging crops at specific developmental stages, such as temperature thresholds during flowering, or by making the timing of field applications more difficult, thus reducing the efficiency of farm inputs.

Synopsis

A large amount of progress has been made in understanding and projecting the effects of future climate change on agricultural production since the previous IPCC report, although significant uncertainties remain. It can now be stated with higher confidence than before that climate change is likely to challenge food security among the world's poorest people located in the low latitudes. It will be less troublesome to agricultural systems in the mid- to high latitude nations (like the USA), at least in the early stages of warming. Adaptation effectively maintains cereal yields in the mid- to high latitudes at or above current levels through moderate amounts of warming (~+4–5 C), but it only protects low latitude cereal yields for a few degrees of warming (~+3 C). The direct effects of rising atmospheric CO_2 levels on crop growth will offset some of the deleterious effects and enhance the beneficial effects of climate change. However, adaptation apart, low latitude cereal yields are projected to fall below current levels with modest warming, in spite of the beneficial effects of rising CO_2. In the mid- to high latitudes, CO_2 offsets yield loss for a while, but after ~+3 C of global mean warming yields of the major cereal crops decline below current levels, again assuming no adaptation. If the climate changes are accompanied by increasing climate variability and frequencies of extreme events, crop yield losses are likely to occur at even smaller mean temperature increases than if variability is unchanged.

Figure 1. Temperate (mid-to high latitudes) vs. Tropics (low latitudes): Percent Change in Cereal Yield vs. Temperature Change (with/without adaptation) from 69 Modeling Studies



BIOGRAPHY FOR WILLIAM E. EASTERLING

Dr. William E. Easterling is the Director of the Penn State Institutes of Energy and the Environment and Professor of Geography and Earth System Science. On July 1, 2007 he will become Dean of the College of Earth and Mineral Sciences at Penn State. He received his Ph.D. in Geography and Climatology from the University of North Carolina at Chapel Hill and has held posts at Resources for the Future, and the University of Nebraska's Department of Agricultural Meteorology. He is an internationally known expert on global climate change focusing particularly on the implications for agricultural production, food security and related global environmental change. Dr. Easterling is the convening lead author for the chapter on food, forestry, and fisheries in the upcoming Intergovernmental Panel on Climate Change Fourth Assessment Report. He has served on and chaired numerous committees and advisory groups for the National Oceanic and Atmospheric Administration, NASA, the National Science Foundation, and the National Research Council. His responsibilities with the Institutes of the Environment are to increase the visibility and integration of Penn State's environmental science and engineering by the hiring of new faculty positions and the fostering of interdisciplinary research, education and outreach. Dr. Easterling is helping coordinate a new energy research initiative at Penn State focusing on connections between transportation, energy, and the environment.

Chairman GORDON. Thank you, Dr. Easterling.

Dr. Burkett, you are recognized for five minutes.

STATEMENT OF DR. VIRGINIA BURKETT, CHIEF SCIENTIST FOR GLOBAL CHANGE RESEARCH, U.S. GEOLOGICAL SURVEY, U.S. DEPARTMENT OF THE INTERIOR

Dr. BURKETT. My name is Virginia Burkett and it is a pleasure to be here, Mr. Chairman and Committee. I am a scientist with the U.S. Geological Survey and one of eight co-authors of the coastal chapter. My co-authors are listed here from many countries.

The key policy-relevant findings in the coastal chapter are number one, that coasts are already experiencing the adverse consequences of climate-related hazards and sea-level rise. Number two, coasts will be exposed to increasing risk over the coming decades as sea level rises and the climate changes. Number three, the impact of climate change on coasts is exacerbated by increased human development activity which we found to have a greater impact on coasts during the past century than did climate change. Four, adaptation of coasts for developing countries will be more challenging than for developed nations simply due to constraints on adaptive capacity, whether technological, financial or institutional. Five, adaptation costs are much less generally than the cost of inaction, and finally, the unavoidability of sea-level rise conflicts with present-day human development patterns and trends.

USGS
science for a changing world

Climate Change 2007:
Impacts, Adaptations and Vulnerability

Highlights of the Coastal Chapter,
IPCC Fourth Assessment Report

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Key Policy Relevant Findings

1. Coasts are experiencing the adverse consequences of hazards related to climate and sea level rise.
2. Coasts will be exposed to increasing risks over coming decades due to many compounding climate-change factors.
3. The impact of climate change on coasts is exacerbated by increasing human-induced pressures.
4. Adaptation for the coasts of developing countries will be more challenging than for coasts of developed countries, due to constraints on adaptive capacity.
5. Adaptation costs are much less than the costs of inaction.
6. The unavoidability of sea-level rise even in the longer term frequently conflicts with present-day human development patterns and trends.

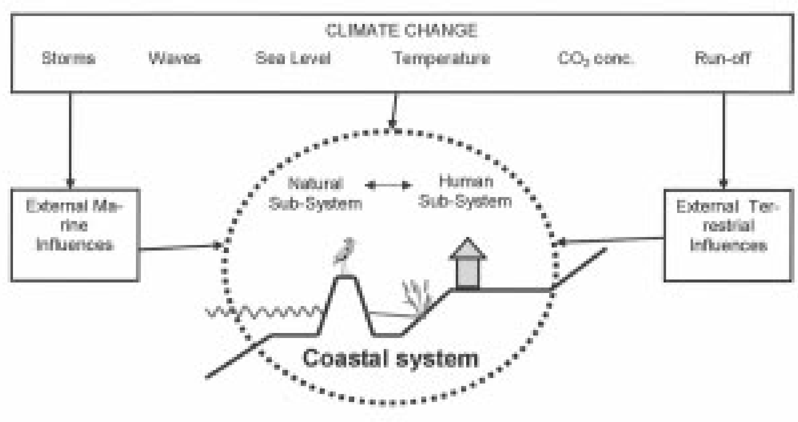
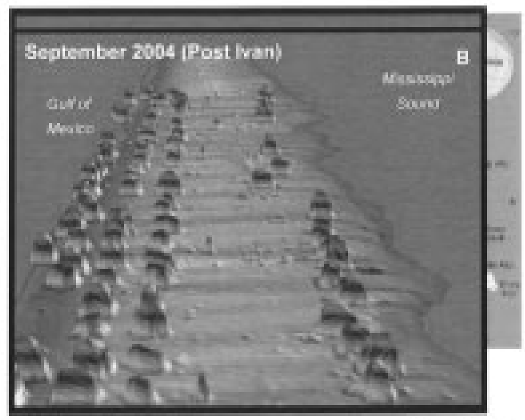


Figure 6.1 Climate change and the coastal system showing the major climate change factors, including external marine and terrestrial influences

We examined potential effects of climate change on all major types of coastal systems ranging from coastal wetlands to coral reefs to sea grasses to barrier islands and coastal forests and the top line of this graphic shows the six major drivers of change, the first on the left being increase in tropical storm intensity and wave regime, accelerated sea-level rise, increased temperature, increased CO_2 concentrations and finally, changes in runoff which are due to changes in precipitation and also due to the increase in temperature which causes a faster evaporation of surface waters. Each of these climate-related processes plays an important role in structuring coastal systems but all coastal systems are not equally vulnerable. A wetland in one place is not the same as a wetland in another place in terms of its vulnerability.

Hotspots of Societal Vulnerability: US Coastal Zones

Atolls and Small Islands
New Orleans
Mississippi Delta
Arctic Coast
Coral Reefs
Gulf of Mexico Coast
Florida



Dauphin Island before Ivan, after Ivan, after Katrina

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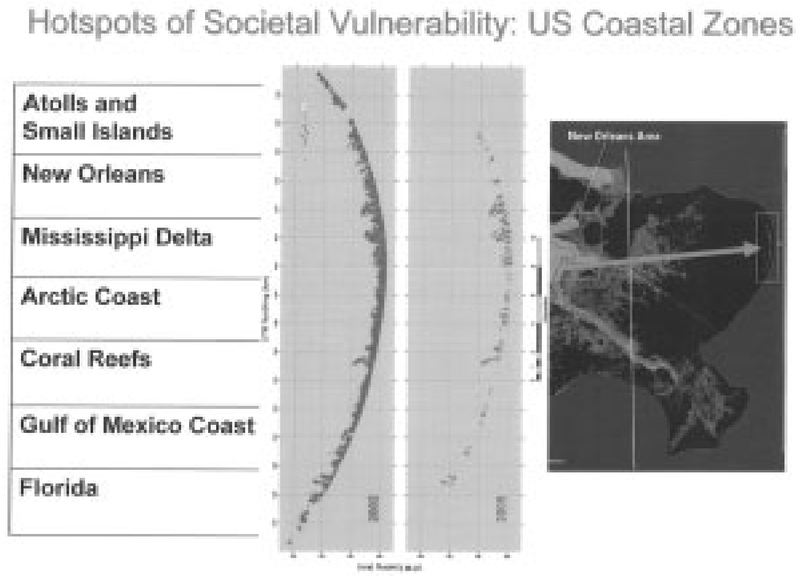
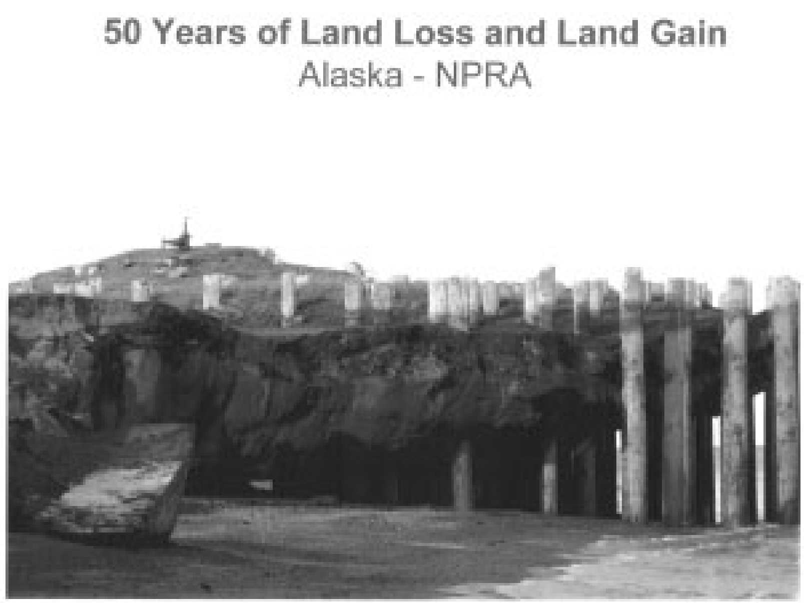




This slide lists some of the key vulnerabilities of coastal systems in America. Our chapter dealt with all of the world of course but these are some things I pulled out from one of our tables. For example there are over 1,000 U.S.-protected islands in the Pacific, many of which have a mean elevation of three to 10 feet above sea level. Sea-level rise will affect the water supply of many of these islands a long time before the population is flooded. Shifting closer to the mainland at Dauphin Island, Alabama, here is one of our LiDAR (Light Detection And Ranging) images from our St. Pete lab. The little green things with the tops that are red, those are houses. You can see the Gulf of Mexico on the left and the Mississippi Sound and you can see the road going down the island prior to Hurricane Ivan. The impacts of Hurricane Ivan on this island and Hurricane Katrina provide a good illustration of how the predicted increase in hurricane intensity might affect low-lying coastal barriers of the Southeast along the Gulf of Mexico and the Atlantic border.

The IPCC report contains a cross-chapter study of mega deltas, which are among the most vulnerable regions to climate change in the world. Human societies in Asian mega deltas are considered most vulnerable because of their exposure to risk, high population concentration and lack of adaptive capacity. In North America, the Mississippi River delta is the best example and it is ranked as highly vulnerable in our chapter. In the subsiding Mississippi delta, even minor changes in the rate of sea-level rise will have serious impacts on coastal wetlands and barrier islands which protect the city of New Orleans, for example. Everything in red and yellow on this slide was converted to open water during the past 70 years, and if you look at the landfall of Hurricane Katrina, you can see it in yellow there and you can see the land loss in the New Orleans area just overnight in addition to what was shown on the earlier side, and that is what the Chandeleur Island chain looks like now. The left is before the storm and to the right is after the storm.

And here it looks like the flipside, like you just turned the Louisiana land loss map upside down and it is land loss in coastal Alaska where the land is sinking, the permafrost is thawing. It is 70 percent ice, the substrate is there. The sea ice has retreated and so the erosion of wave attack along that coast has accelerated and it looks like it has accelerated, and this is just 50 years of land change. There are substantial investments in infrastructure here like the National Petroleum Reserve in Alaska. This well here was drilled in 1970s. You can see how the land has collapsed under it and the erosion has affected the shore face, and in addition to the infrastructure there, there are many native communities that will have to move.

[The prepared statement of Dr. Burkett follows:]

PREPARED STATEMENT OF VIRGINIA BURKETT

Mr. Chairman and Members of the Committee, as a Lead Author of the Fourth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC), Working Group II, I am pleased to present a summary of the findings found in Chapter 6, *"Coastal Systems and Low-Lying Areas,"* of the report. First, I want to acknowledge my co-authors, with whom I have collaborated over the past three years to develop this assessment of climate change impacts, adaptation and vulnerability in coastal systems:

> Robert J. Nicholls (UK), Poh Poh Wong (Singapore), Jorge Codignotto (Argentina), John Hay (New Zealand), Roger McLean (Australia), Sachooda Ragoonaden (Mauritius), and Colin D. Woodroffe (Australia)

Dr. Nichols and Dr. Wong served as Convening Lead Authors for the coastal chapter.

I deeply appreciate being nominated by the United States Government to serve as a Lead Author of the Fourth Assessment Report, as well as the prior assessment report published by the IPCC in 2001. The charge to the authors of the Fourth Assessment Report by the IPCC was to develop a balanced, comprehensive and policy-relevant assessment of current knowledge, which:

— evaluates the full range of knowledge (e.g., positive and negative effects),
— is policy-relevant, not prescriptive,
— is supported by clear evidence,
— is clear about underlying assumptions, and confidence levels,
— emphasizes new knowledge since the IPCC's Third Assessment Report,
— is more concise than the Third Assessment Report, with better connections to Working Groups I and III, and with wider use on non-English sources of knowledge,
— and is lucidly written.

The IPCC Working Group II contribution to the Fourth Assessment Report was guided by a complex, open and peer-reviewed process that engaged several hundred authors and roughly 50 review editors from 47 countries; and well over 800 expert reviewers. The coastal chapter authors responded to roughly 1,500 comments received during external peer and government reviews, and many of these comments led us to additional new literature about coasts and climate change. I estimate that our coastal chapter writing team reviewed between 500 and 700 scientific journal articles, books and scientific proceedings published since 2000.

For each chapter of the IPCC report, two or three Review Editors were selected by the IPCC from the lists of experts nominated by the governments. The three Review Editors assigned to the coastal chapter were: Job Dronkers (Netherlands), Geoff Love (Australia), and Jin-Eong Ong (Malaysia). The main duty of these scientists was to ensure that we responded appropriately to comments on our draft chapter from experts and the governments during two separate cycles of review. With each review the scope of the material contained in the chapter expanded and the consensus of the authors emerged fairly easily in our case as we identified the key drivers and their impacts.

Please note that we indicated our confidence levels in these statements and many of our scientific findings by using endnotes (e.g., High Confidence) or by using the IPCC accepted terminology for assessing the likelihood of an outcome having occurred or occurring the in the future. When IPCC authors use the term "very likely" in a sentence, for example, the authors have reached a consensus that an outcome has an estimated probability of 90 to 99 percent. This terminology was used across all of the IPCC Working Group II chapters. Also, please note that for every statement made, there is supporting literature cited in the coastal chapter.

Key Policy-Relevant Findings

Since the Third Assessment Report was published in 2001, our understanding of the implications of climate change for coastal systems and low lying areas (henceforth referred to as 'coasts') has increased substantially. In the Executive Summary of the coastal chapter, we identified six important policy-relevant findings, which are extracted below from our text:

1. Coasts are experiencing the adverse consequences of hazards related to climate and sea level rise (very high confidence). They are highly vulnerable to extreme events, such as storms which impose substantial costs on coastal societies. Annually, about 120 million people are exposed to tropical cyclone hazards which had killed 250,000 people from 1980 to 2000. Through the 20th century, global rise of sea level contributed to increased coastal inundation, erosion and ecosystem losses, but with considerable local and regional variation due to other factors. Late 20th Century effects of rising temperature include loss of sea ice, thawing of permafrost and associated coastal retreat, and more frequent coral bleaching and mortality.

2. Coasts will be exposed to increasing risks over coming decades due to many compounding climate-change factors (very high confidence). Anticipated climate-related changes include: an accelerated rise in sea level of up to 0.6 m or more by 2100; further rise in sea surface temperatures by up to 3 C; an intensification of tropical and extratropical cyclones; larger extreme waves and storm surges; altered precipitation/run-off; and ocean acidification. These phenomena will vary considerably at regional and local scales, but the impacts are virtually certain to be overwhelmingly negative. Corals are threatened with increased bleaching and mortality due to rising sea surface temperatures. Coastal wetland ecosystems, such as salt marshes and mangroves, are especially threatened where they are sediment starved or constrained on their landward margin. Degradation of coastal ecosystems, especially wetlands and coral reefs, has serious implications for the well-being of societies dependent on the coastal ecosystems for goods and services. Increased flooding and the degradation of freshwater, fisheries and other resources could impact hundreds of millions of people and socio-economic costs will escalate as a result of climate change for coasts.

3. The impact of climate change on coasts is exacerbated by increasing human-induced pressures (very high confidence). Utilization of the coast increased dramatically during the 20th century and this trend is virtually certain to continue through the 21st century. Under the Special Report on Emissions Scenarios (SRES), the coastal population could grow from 1.2 billion people (in 1990) to 1.8 to 5.2 billion people by the 2080s, depending on assumptions about migration. Increasing numbers of people and assets at risk at the coast are subject to additional stresses by land-use and hydrological changes in catchments, including dams that reduce sediment supply to the coast. Populated deltas (especially Asian mega-deltas), low lying coastal urban areas, and atolls are key societal hotspots of coastal vulnerability, occurring where the stresses on natural systems coincide with low human adaptive capacity and high exposure. Regionally, south, southeast and east Asia, Africa and small islands are most vulnerable. Climate change therefore reinforces the desirability of managing coasts in an integrated manner.

4. Adaptation for the coasts of developing countries will be more challenging than for coasts of developed countries, due to constraints on adaptive capacity (high confidence). While physical exposure can significantly influence the vulnerability for both human populations and natural systems, a lack of adaptive capacity is often the most important factor that creates a hotspot of human vulnerability. Adaptive capacity is largely dependent upon development status. Developing nations may have the political or societal will to protect or relocate people who live in low-lying coastal zones, but without the necessary financial and other resources/capacities, their vulnerability is much greater than a developed nation in an identical coastal setting. Vulnerability will also vary between developing countries, while developed countries are not insulated from the adverse consequences of extreme events.

5. Adaptation costs for vulnerable coasts are much less than the costs of inaction (high confidence). Adaptation costs for climate change are much lower than damage costs without adaptation for most developed coasts, even considering only property losses and human deaths. As post event impacts on coastal businesses, people, housing, public and private social institutions, natural resources, and the environment generally go unrecognized in disaster cost accounting, the full benefits of adaptation are even larger. Without adaptation, the high-end sea level scenarios combined with other climate change (e.g., increased storm intensity) are as likely as not to render some islands and low-lying areas uninhabitable by 2100, so effective adaptation is urgently required.

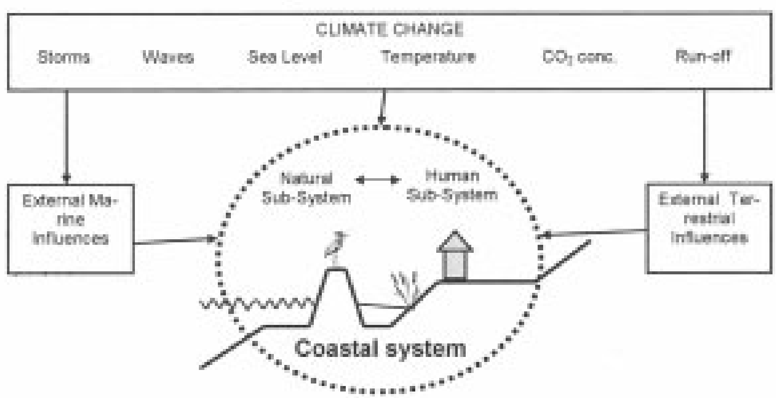
6. The unavoidability of sea level rise even in the longer-term frequently conflicts with present day human development patterns and trends (high confidence). Sea level rise has substantial inertia and will continue beyond 2100 for many centuries. Irreversible breakdown of the West Antarctica and/or Greenland ice sheets, if triggered by rising temperature, would make this long-term rise significantly larger, ultimately questioning the viability of many coastal settlements across the globe. The issue is reinforced by the increasing human use of the coastal zone. Settlement patterns also have substantial inertia, and this issue presents a challenge for long-term coastal spatial planning. Stabilization of climate could reduce the risks of ice sheet breakdown, and reduce but not stop sea level rise due to thermal expansion. Hence, it is now more apparent than in the Third Assessment Report that the most appropriate response to sea level rise for coastal areas is a combination of adaptation to deal with the inevitable rise, and mitigation to limit the long-term rise to a manageable level.

Human Development Patterns Interact With Climate Drivers and Impacts on Coastal Systems

Coasts are very likely to be exposed to increasing risks due to climate change and sea level rise and the effect will be exacerbated by increasing human-induced pressures on coastal areas. One of our main conclusions is that the influence of human development activities in coasts and adjacent watersheds generally had a more important influence on coastal systems than did climate change during the past century. Utilization of the coast increased dramatically during the 20th Century, a trend that seems certain to continue through the 21st Century. Coastal population growth in many of the world's deltas, barrier islands, and estuaries has led to widespread conversion of natural coastal landscapes to agriculture, aquaculture, silviculture, as well as industrial and residential uses. It has been estimated that 23 percent of the world's population lives both within 100 km distance of the coast and less than 100 m above sea level, and population densities in coastal regions are about three times higher than the global average.

The top bar in the figure below lists the six climate change drivers that are likely to affect coastal ecosystems, which are generally influenced by a combination of natural processes and human development activity. During the preparation of the coastal chapter of the IPCC Third Assessment report, sea level rise was the focus of the available literature relating to climate change and coastal impacts. Sea level rise still dominates the literature on coastal areas and climate change, but our review shows that more information is now available regarding the effects of increases in temperature, storm intensity and waves, increased carbon dioxide (CO_2) concentration, and changes in run-off.

Figure 6.1 in the Coastal Chapter, IPCC Fourth Assessment Report, 2007. Climate change and the coastal system showing the major climate change factors, including external marine and terrestrial influences.



Increases of extreme sea levels due to changes in storm characteristics are generally of more concern for populated coastal areas than mean sea level rise. The coastal chapter reports that climate models suggest both tropical and extratropical storm intensity will increase as the temperature of the atmosphere and sea surface rise—this implies additional coastal impacts than attributable to sea level rise alone, especially for tropical and mid-latitude coastal systems. An increase in the intensity of tropical cyclones entering the Gulf of Mexico, for example, is consistent with the observed changes in sea surface temperature in the equatorial Atlantic Ocean where Gulf of Mexico hurricanes form. Changes in other storm characteristics are less certain and the number of tropical and extra-tropical storms might even reduce. Similarly, extreme wave heights will likely increase with more intense storms. Changes in run-off driven by changes to the hydrological cycle appear likely, but the uncertainties are large. Increases in atmospheric CO_2 concentrations can enhance photosynthesis and productivity of plant communities, but because plants respond differently to the increase in CO_2, competition among plant species may alter the structure of coastal plant communities. Increasing atmospheric CO_2 levels can adversely affect coral reefs by decreasing the pH of the ocean, which decreases the carbonate saturation of seawater. The table below summarizes some of the impacts on coastal systems that are discussed in our chapter.

Table 6.2 of the Coastal Chapter, IPCC Fourth Assessment Report, 2007.
Trend in climate drivers identified in Figure 6.1 due to climate change and their main physical and ecosystem effects on coastal systems and low-lying areas.
(Nature of Change: ↑ increase; R regional variability; ? uncertain).

Climate Driver (change)		**Main Physical and Ecosystem Effects (discussed in Section 6.4.1)**
CO_2 concentration (↑)		Increased CO_2 fertilization; Decreased seawater pH (or 'ocean acidification') negatively impacting coral reefs and other pH sensitive organisms.
Sea surface temperature (SST) (↑, R)		Increased stratification/changed circulation; Reduced incidence of sea ice at higher latitudes; Increased coral bleaching and mortality (see Box 6.1); Poleward species migration; Increased algal blooms.
Sea level (↑, R)		Inundation, flood and storm damage (see Box 6.2); Erosion; Saltwater Intrusion; Rising water tables/ impeded drainage; Wetland loss (and change).
Storm	Intensity (↑, R)	Increased extreme water levels and wave heights; Increased episodic erosion, storm damage, risk of flooding and defense failure (see Box 6.2);
	Frequency (?, R)	Altered surges and storm waves and hence risk of storm damage and flooding (see Box 6.2).
	Track (?,R)	
Wave climate (?, R)		Altered wave conditions, including swell; Altered patterns of erosion and accretion; Re-orientation of beach planform.
Run-off (R)		Altered flood risk in coastal lowlands; Altered water quality/salinity; Altered fluvial sediment supply; Altered circulation and nutrient supply.

We considered how these climate-related variables would influence the sustainability of each major coastal system and coral reefs. A summary with examples from our chapter is presented below (note: the specific examples highlighted here comprise only a few of the impacts described in the chapter):

Beaches, rocky shorelines, and cliffed coasts

Most of the world's sandy shorelines retreated during the past century and sea level rise is one underlying cause. One half or more of the Mississippi and Texas shorelines eroded at average rates of 3.1 to 2.6 m/yr since the 1970s, while 90 percent of the Louisiana shoreline eroded at a rate of 12.0 m/yr. In Nigeria shoreline retreat rates up to 30 m/yr are reported and in the United Kingdom 67 percent of the coastline experienced a landward retreat of the low-water mark over the past century. An acceleration in sea level rise will widely exacerbate beach erosion around the globe, although the local response will depend on the total sediment budget. Even gravel beaches and soft rock cliffs are vulnerable to climate change via changes in storm intensity, sea level rise and changes in precipitation patterns, which affect the physical processes that govern the evolution of these coastal systems. The combined effects of beach erosion and storms can lead to the erosion or inundation of other coastal systems as well. For example, an increase in wave heights in coastal bays is a secondary effect of sandy barrier island erosion in Louisiana, and increased wave heights have enhanced erosion rates of bay shorelines, tidal creeks, and adjacent wetlands.

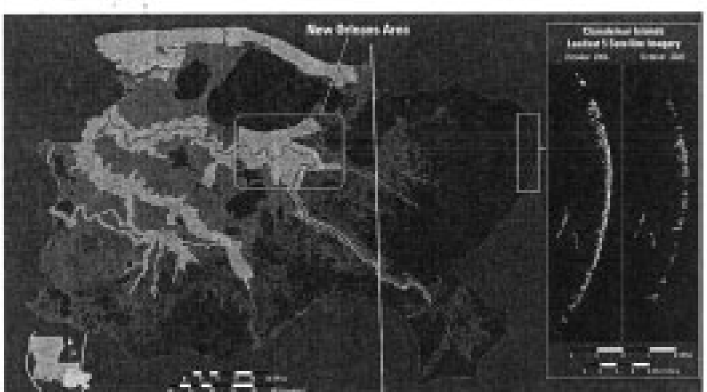
Deltas

Deltas have long been recognized as highly sensitive to sea level rise. Rates of relative sea level rise can greatly exceed the global average rate of sea level rise in many heavily populated deltaic areas due to subsidence, including the Chao Phraya delta, the Mississippi River delta, and the Changjiang River delta because of human activities. Natural subsidence due to autocompaction of sediment under its own weight is enhanced by sub-surface fluid withdrawals and drainage, which increases the potential for inundation, especially for the most populated cities on these deltaic plains (i.e., Bangkok, New Orleans, and Shanghai). Most of the land area of Bangladesh consists of the deltaic plains of the Ganges, Brahmaputra, and Meghna rivers. Accelerated global sea level rise and higher extreme water levels may have acute effects on human populations of Bangladesh (and parts of West Bengal, India).

Sea level rise poses a particular threat to deltaic environments, especially when coupled with the synergistic effects of other climate and human pressures. These effects are best illustrated in large deltas with an area greater than 100,000 km^2 (called "mega-deltas" in the IPCC report) due to their often large populations and important environmental services. The problems of climate change in mega-deltas are reflected throughout the IPCC Working Group II Fourth Assessment Report where a number of chapters considered their vulnerability from complementary perspectives. The coastal chapter describes the vulnerability of people living in delta systems across the globe, and concludes that the large populated Asian mega-deltas are especially vulnerable to climate change. The Mississippi River delta is another mega-delta that is considered highly vulnerable to the impacts of climate change. Chapter 10 (*Asia Region*) examines the Asian mega-deltas in more detail, while Chapter 5 (*Food, Fiber, and Forest Products*) examines the threats to fisheries in the lower Mekong and Mekong delta due to climate change. Hurricane Katrina made landfall on the Mississippi delta in Louisiana, and the text box below from the coastal chapter considers different aspects of this important event, which gives an indication of the likely impacts if tropical storm intensity continues to increase. Lastly, the Polar Chapter (Chapter 15) considers the specific problems of Arctic mega-deltas where the advance/retreat of Arctic marine deltas is highly dependent on the protection afforded by near-shore and land-fast sea ice, which is disappearing rapidly in the Arctic Ocean. The Mackenzie and Lena river deltas are fed by the largest Arctic rivers of North America and Eurasia, respectively. In contrast to non-polar mega-deltas, the physical development and ecosystem health of these deltaic systems are strongly controlled by cryospheric processes and hence highly susceptible to the effects of climate change.

Hurricane Katrina impacts on coastal ecosystem services in the Mississippi Delta (excerpts from Box 6.4 in the IPCC Fourth Assessment Report, Coastal Chapter)

Whereas an individual hurricane event cannot be attributed to climate change, it can serve to illustrate the consequences for ecosystem services if the intensity and/or frequency of such events were to increase in the future. One result of Hurricane Katrina, which made landfall in coastal Louisiana on August 29, 2005, was the loss of 388 km^2 of coastal wetlands, levees, and islands that flank New Orleans in the Mississippi River Deltaic Plain. (Hurricane Rita, which struck in September 2005, had relatively minor effects on this part of the Louisiana coast). The Chandeleur Islands, which lie southeast of the city were reduced to roughly half of their former extent during Hurricane Katrina. Collectively, these natural systems serve as the first line of defense against storm surge in this highly populated region. Over 1300 people lost their lives during Hurricane Katrina and the economic losses totaled more than $100 billion. Roughly 300,000 homes and over 1,000 historical and cultural sites were destroyed along the Louisiana and Mississippi coasts. The Chandeleur Islands serve as an important wintering ground for migratory waterfowl and neo-tropical birds; a large population of North American redhead ducks, for example, feed on the rhizomes of sheltered sea grasses leeward of the Chandeleur Islands. Historically the region has ranked second only to Alaska in U.S. commercial fisheries production and this high productivity has been attributed to the extent of coastal marshes and sheltered estuaries of the Mississippi River delta.



Areas in red were converted to open water during the hurricane. Yellow lines on index map of Louisiana show tracks of Hurricane Katrina on right and Hurricane Rita on left (Figure source: U.S. Geological Survey).

Estuaries and lagoons

Sea level rise will generally lead to higher water levels and salt water intrusion in coastal estuaries, thereby tending to shift existing coastal plant and animal communities inland. A globally-intensified hydrologic cycle and regional changes in runoff also portend changes in estuarine water quality. Some of the greatest potential impacts of climate change on estuaries may result from changes in physical mixing characteristics caused by changes in freshwater runoff. Changes in the timing of freshwater delivery to estuaries, for example, could lead to a decoupling of the juvenile phases of many estuarine and marine fishery species with available nursery habitat. Freshwater inflows into estuaries influence water residence time, nutrient delivery, vertical stratification, salinity, and control of phytoplankton growth rates in estuaries. Increased water temperature could affect algal production and the availability of light, oxygen and carbon for other estuarine species. As estuarine water temperature increases, algal blooms are likely to become more common.

An effect of rising sea level in some hypersaline lagoonal systems, such as the Laguna Madre of Mexico and Texas, will be greater water depths, leading to increased tidal exchange and hence reduced salinity. As an analogue, the lowering of salinity in the Laguna Madre since 1949, attributed primarily to the dredging of the Gulf Intracoastal Waterway and increased drainage from agricultural lands, has shifted seagrass species from the highly salt tolerant shoalgrass (*Halodule wrightii*) to manatee grass (*Syringodium filiforme*), which has a lower salinity tolerance.

A projected increase in the intensity of tropical cyclones and other coastal storms could alter bottom sediment dynamics, organic matter inputs, phytoplankton and fisheries populations, salinity and oxygen levels, and biogeochemical processes in estuaries and lagoons.

Mangroves, Salt Marshes and Sea Grasses

Coastal vegetated wetlands are sensitive to climate change because their location is intimately linked to sea level. Several global and regional analyses suggest significant losses of coastal vegetated wetlands during the 21st Century under scenarios of accelerated sea level rise, with global losses in one study estimated at 33 percent and 44 percent given a 36 cm and 72 cm rise in sea level from 2000 to 2080, respectively. However, wetland processes are complex and the impacts on any particular tract of marsh or forest will depend upon local rates of sediment accretion, elevation, vertical land motion (such as subsidence) and other local processes. Changes in storm intensity can also affect vegetated coastal wetlands (see box on Hurricane Katrina effects).

Climate change will likely have its most pronounced effects on coastal marshes through the alteration of hydrologic regimes, specifically, changes in the timing and volume of water delivered to the coast. Other variables—altered biogeochemistry, altered amounts and pattern of suspended sediments loading, fire, oxidation of organic sediments and the physical effects of wave energy—may also play important roles in determining regional and local impacts. Regional losses of coastal marsh are expected to be most severe on the Atlantic and Gulf of Mexico coasts of North and Central America, the Caribbean, the Mediterranean, the Baltic and most small island regions due to their low tidal range.

Mangrove communities are likely to show a blend of positive (e.g., from higher levels of CO_2 and temperature) and negative (e.g., increased saline intrusion and erosion) effects, which will largely depend on site specific factors. Increasing salinity has played a role in the expansion of mangroves into adjacent marshes in the Florida Everglades and throughout southeastern Australia during the past 50 years. Increased salinity of coastal waters since 1950 has contributed to the decline of cabbage palm forests in Florida and baldcypress forests in Louisiana.

Changes in salinity and temperature and increased sea level, atmospheric CO_2, and storm activity will alter seagrass distribution, productivity, and community composition. Increases in the amount of dissolved CO_2 and, for some species, (bicarbonate) HCO_3-present in aquatic environments will lead to higher rates of photosynthesis in submerged aquatic vegetation, similar to the effects of CO_2 enrichment on most terrestrial plants, but these changes in aquatic carbon availability can also increase the growth of suspended or epiphytic algae that reduce light needed for sea grass survival.

Coral Reefs

Coral "bleaching" refers to the loss of symbiotic algae and/or their pigments and has been observed on many reefs since the early 1980s. Slight paling occurs naturally in response to seasonal increases in sea surface temperature and solar radiation. Corals bleach white in response to anomalously high sea surface temperature (about 1°C above average seasonal maxima, often combined with high solar radiation). If bleaching is prolonged, or if sea surface temperature exceeds 2°C above seasonal maxima, corals die. The most severe world-wide bleaching events appear to be associated with El Niño events. Major bleaching events were observed in 1982–83, 1987–88, 1994–95, and most extensively in 1998. Since 1998 there have been several extensive bleaching events. For example, in 2002 bleaching occurred on much of the Great Barrier Reef and reefs in the eastern Caribbean experienced a massive bleaching event in late 2005, one of the hottest years on record.

There is very limited evidence that corals can adapt to increases in temperature; corals and other calcifying organisms (e.g., molluscs, foraminifers) are considered extremely susceptible to increases in sea surface temperature that are likely during the coming decades. Bleaching events reported in recent years have already impacted many reefs, and their more frequent recurrence is very likely to further reduce both coral cover and diversity on reefs over the next few decades. There are other threats to reefs associated with climate change apart from coral bleaching, in addition to non-climatic stresses such as overfishing, pollution and sediment influxes. Increased concentrations of CO_2 in seawater will lead to ocean acidification, which will affect aragonite saturation state and reduce calcification rates of calcifying organisms such as corals. An increase in tropical storm intensity would further endanger coral reefs with impacts ranging from minor breakage of fragile corals to destruction of the majority of corals on a reef.

The bleaching of corals above a certain sea surface temperature is a threshold-type response that illustrates the complex, nonlinear behavior of coastal systems to changes in climate. Another temperature-related threshold is the melting of polar permafrost which results in coastal erosion. Several other types of thresholds characterize the response of coastal systems to climate change and are reported in the IPCC coastal chapter. The key message is that while some coastal systems do not appear to be vulnerable to the rates of change experienced during the 20th century, they each have a limited capacity to adapt to changes in climate and in many cases there are thresholds at which rapid changes in coastal systems are likely to occur.

Consequences for Human Society

I understand that Dr. Roger Pulwarty from the National Oceanic and Atmospheric Administration is testifying today on Chapter 17 of the IPCC report, titled *Assessment of Adaptation Practices, Options, Constraints and Capacity.* Dr. Pulwarty focuses on adaptation strategies that society can use to adjust to climate change, to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

As Dr. Pulwarty points out, adaptation procedures could increase societal resilience to the negative consequences of climate change in the future. That said, since much of the world's population is located at or near the coast and coastal systems provide many valuable goods and services globally, the changes that we anticipate in coastal systems will have widespread societal consequences. In our chapter we presented a synthesis of current knowledge about coastal impacts of climate change for six different socio-economic sectors, as highlighted below:

1. *Freshwater resources*—Saltwater intrusion due to sea level rise alone will have serious economic effects for many coastal communities. Although the coast contains a substantial proportion of the world's population, it has a much smaller proportion of the global renewable water supply, and the coastal population is growing faster than elsewhere, exacerbating this imbalance. Freshwater supply problems due to climate change are most likely in developing countries with a high proportion of coastal lowland, arid and semi-arid coasts, coastal megacities (particularly in the Asia-Pacific region), and small island states.
2. *Agriculture, forestry, and fisheries*—Climate change is expected to have impacts on agriculture and, to a lesser extent, on forestry. Climate variability and change also impacts fisheries in coastal and estuarine waters. More frequent extreme climate events, together with higher rainfall intensity and longer dry spells, may impact negatively on crop yields. Cyclone landfall causing floods and destruction, have negative impacts on coastal areas, e.g., coconuts in India, or sugar cane and bananas in Queensland. Rising sea level is predicted to have negative impacts on coastal agriculture. Detailed modelling of inundation implies significant changes to the number of rice crops possible in the Mekong delta under 20–40 cm of relative sea level rise. Rising sea level potentially threatens inundation and soil salinization of palm oil and coconuts in Benin and Cote d'Ivoire and mangoes, cashew nuts and coconuts in Kenya.

3. *Human settlements, infrastructure, and migration*—Climate change and sea level rise affects coastal settlements and infrastructure in several ways. Sea level rise raises extreme water levels with possible increases in storm intensity portending additional climate impacts on many coastal areas, while salt-water intrusion may threaten water supplies. The degradation of natural coastal systems due to climate change, such as wetlands, beaches and barrier islands removes the natural defenses of coastal communities against storm surge. Hundreds of millions of people are vulnerable to flooding due to sea level rise, especially in densely populated and low-lying settlements where adaptive capacity is relatively low and which already face other challenges such as tropical storms or local coastal subsidence. The numbers affected will be largest in the mega-deltas of Asia. Africa is also likely to see a substantially increased exposure, with East Africa (Mozambique) having particular problems due to the combination of tropical storm landfalls and large projected population growth in addition to sea level rise.
4. *Human health*—Coastal communities, particularly in low income countries, are vulnerable to a range of health effects due to climate variability and long-term climate change, particularly extreme weather and climate events (such as cyclones, floods, and droughts). Communities that rely on marine resources for food are vulnerable to climate-related impacts, in both health and economic terms. Temperature changes play a role in determining human health risks, such as from cholera and other enteric pathogens (*Vibrio parahaemolyticus*), harmful algal blooms, and shellfish and reef fish poisoning.
5. *Biodiversity*—The distribution, productivity, and diversity of species in coastal ecosystems is sensitive to variations in weather, climate, and sea level. Changes in the ranges of invertebrates and waterfowl have already been observed in some coastal regions in response to increases in temperature. It is clear, however, that responses of intertidal and shallow marine organisms are more complex than simply latitudinal shifts related to temperature increase, with complex biotic interactions superimposed on the abiotic.
6. *Recreation and tourism*—Climate change may influence tourism directly via the decision-making process by influencing tourists to choose different destinations; and indirectly as a result of sea level rise and resulting coastal erosion. In general, air temperature rise is most important to tourism, except where factors such as sea level rise promotes beach degradation and viable adaptation options (e.g., nourishment or recycling) are not available. Other likely impacts of climate change on coastal tourism are due to coral reef degradation. Temperature and rainfall pattern changes may impact water quality in coastal areas and this may lead to more beach closures.

Key Vulnerabilities and Hotspots

A comprehensive assessment of the potential impacts of climate change must consider at least three components of vulnerability: exposure, sensitivity, and adaptive capacity. The coastal chapter broadly characterizes the sensitivity and natural adaptive capacity (or resilience) of several major classes of coastal environments to changes in climate and sea level rise. Differences in geological, oceanographic, and biological processes can lead to substantially different impacts for a single type of coastal system (mangroves for example) at different locations. Some global patterns of vulnerability among systems became evident, however, and are listed below, with the first three generally at a higher level of risk:

— deltas/estuaries (especially populated mega-deltas)
— coral reefs (especially atolls)
— ice-dominated coasts
— low-lying coastal wetlands
— small islands
— sand and gravel beaches
— soft rock cliffs

Our understanding of human adaptive capacity is less developed than our understanding of responses by natural systems, which limits the degree to which we were able to quantify societal vulnerability in the world's coastal regions. Nonetheless, several key aspects of human vulnerability emerged. It is apparent that multiple and concomitant non-climate stresses will exacerbate the impacts of climate change on most natural coastal systems, leading to much larger and detrimental changes in the 21st Century than those of the 20th Century. The table below summarizes some of the key hotspots of vulnerability that arise from the combination of natural and societal factors. Note than some examples such as atolls and small islands and deltas/mega-deltas recur in this table, stressing their high vulnerability.

Table 6.6 of the Coastal Chapter, IPCC Fourth Assessment Report, 2007.
Key hotspots of societal vulnerability in coastal zones.

Controlling factors	**Examples from this Chapter**
Human communities in low-lying coastal areas, especially those facing major technical or economic constraints with respect to adaptation	Atolls and small islands, New Orleans
Coastal areas where adaptation will deliver great benefits but where substantial barriers to implementation exist (costs, institutional, environmental, etc.)	Venice, Asian megadeltas
Coastal areas that are subject to multiple natural and human-induced stresses, such as subsidence or declining natural defenses	Mississippi, Nile and Asian megadeltas, Netherlands, Mediterranean, Maldives
Coastal areas already experiencing adverse effects of temperature rise	Coral reefs, Arctic coasts (USA, Canada, Russia), Antarctic peninsula
Coastal areas exposed to significant storm surge hazards	Bay of Bengal, Gulf of Mexico/Caribbean, Rio de la Plata/Parana delta, North Sea
Coastal areas where freshwater resources are likely to be particularly and adversely affected by climate change	W. Africa, W. Australia, Atolls and small islands
Coastal areas where economies are highly dependent upon tourism and major adverse effects on tourism are likely	Caribbean, Mediterranean, Florida, Thailand, Maldives
Highly sensitive coastal systems where the scope for inland migration is limited.	Many developed coasts, Low small islands, Bangladesh

The coastal chapter contains an assessment of the costs of sea level rise, storm damage and erosion in the world's coastal regions. Since the IPCC Third Assessment Report there has been significant progress in moving from classical cost-benefit analysis to assessments that integrate monetary, social, and natural science criteria. Under current climate conditions developing countries bear the main human burden of climate related extreme events, but it is equally evident that developed countries are not insulated from disastrous consequences.

Tropical cyclones have major economic, social and environmental consequences for coastal areas. Up to 119 million people are on average exposed every year to tropical cyclone hazards. Worldwide, from 1980 to 2000, a total of more than 250,000 deaths have been associated with tropical cyclones, of which 60 percent occurred in Bangladesh. (This is less than the 300,000 killed in Bangladesh in 1970 by a single cyclone.) The death toll has been reduced in the past decade due largely to improvements in warnings and preparedness, wider public awareness and a stronger sense of community responsibility. The most exposed countries have densely populated coastal areas, often located on mega-deltas (China, India, the Philippines, Japan, Bangladesh).

Between 1980 and 2005, the United States sustained 67 weather-related disasters each with an overall damage cost of at least U.S. $1 billion. Coastal States in the southeast United States experienced the greatest number of such disasters. The total costs including both insured and uninsured losses for the period, adjusted to 2002, were over U.S. $500 billion. There are differing views as to whether climatic factors have contributed to the increasing frequency of major weather-related disasters along the Atlantic and Gulf coasts of the United States, but the 2007 IPCC Working Group I report and several independent experts support the view that storm intensity has increased in some ocean basins (such as the North Atlantic) and this will continue with global warming. Whichever view is correct, the damage costs associated with these events are undisputedly high, and will increase into the future, especially if development in coastal areas continues. The following figure from the coastal chapter shows the differential vulnerability of developed and developing nations to the effects of sea level rise:

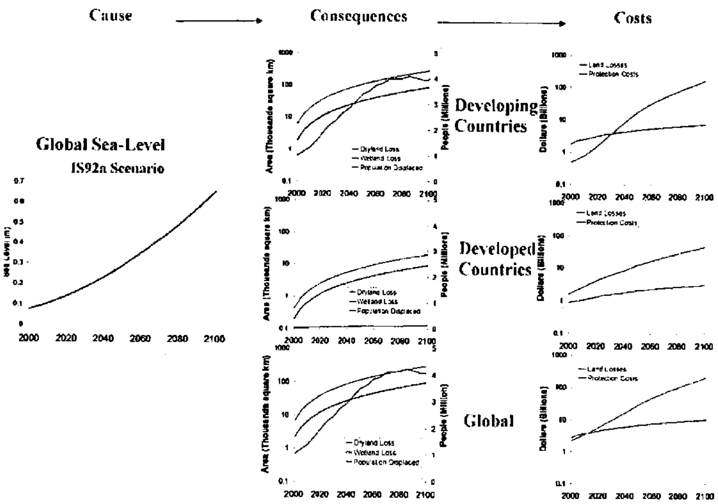


Figure 6.10 of the Coastal Chapter, IPCC Fourth Assessment Report, 2007.
Causes, selected consequences (dryland and wetland loss, people displaced) and the total costs of an assumed sea level rise, for developing and developed countries, and as a global total (based on Tol 2006).

Our chapter concludes with a review of adaptation practices, options and constraints for human settlements in coastal zones. The concept of integrated coastal zone management is discussed with many examples given to illustrate adaptation practices that will help sustain natural coastal systems, their ecological services and the human communities that depend upon them. We do note, however, that recent studies suggest that there are limits to the extent to which natural and human coastal systems can adapt even to the more immediate changes in climate variability and extreme events. For example, short of mitigation, there is little that humans can do to ameliorate the effects of increased sea surface temperature on coral reefs—other than reduce the non-climate related pressures of human activity. Without either adaptation or mitigation the impacts of sea level rise and other climate change such as more intense storms will be substantial, suggesting that some small islands and low-lying coastal areas may become uninhabitable by 2100.

Two things became immensely clear to us as we concluded this assessment: 1) it is much more costly to consider the effects of climate change after the fact than to incorporate climate change into adaptive coastal management now and 2) poor communities (and the poorer parts of communities) and developing coastal and island nations are particularly vulnerable to the impacts of climate change. Poorer coastal societies have a limited ability to adapt or cope with change because they tend to be concentrated in relatively high-risk areas, they have more limited financial and institutional capacities needed for adaptation, and they are often more dependent on climate-sensitive resources such as local water and food supplies.

Thank you, Mr. Chairman, for inviting me to summarize our coastal chapter findings. I will be happy to try and answer any questions that you may have.

Chairman GORDON. Thank you, Dr. Burkett, and to complete your abbreviated introduction, I would like to recognize Mr. Melancon.

Mr. MELANCON. Thank you, Mr. Chairman. I would like to say hello to Dr. Burkett. I guess that is a new phenomenon to call her Burkett. She was Dr. Virginia Vansickel when we worked together back in the 1970s. I was with the regional planning commission.

She was a new, young scientist on the block, so to speak, and has proved her mettle. Back then it was called coastal zone management. Now it is called coastal erosion restoration. We give it a whole lot of different names but as you saw by just the one slide that showed the areas to the east of Louisiana and those that are my district, which is the fastest disappearing district I believe in the United States land-mass-wise. She has done quite credible work. I am proud to call her a friend, a former associate, and I would like to welcome you here and I am sorry I was running late to get here. I am trying to visit with people that are still continuing to flow through my office worried about coastal restoration, hurricane recovery, rebuild and other items that have kept my plate quite full. But it is good seeing you again, Virginia, and welcome.

Chairman GORDON. Dr. Agrawala is recognized for five minutes.

STATEMENT OF DR. SHARDUL AGRAWALA, PRINCETON UNIVERSITY AND ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT (OECD)

Dr. AGRAWALA. Chairman Gordon and Members of the Committee, thank you for the opportunity to testify this morning. I am a Visiting Senior Fellow at the Woodrow Wilson School of Public and International Affairs at Princeton University. I am currently on sabbatical from the Organisation for Economic Co-operation and Development in Paris. A short biography can be found at the end of my testimony.

I served as a Coordinating Lead Author for the chapter on assessment of adaptation practices, options, constraints and capacity in the Fourth Assessment Report of the IPCC. Dr. Pulwarty, sitting next to me, was also on this chapter and will be talking next about some of the implications for the U.S. My testimony will cover some of the broad findings on adaptation coming out of this chapter.

I would like to offer five take-home messages. The first point I would like to make is that climate policy is not about making a choice between adapting to and mitigating climate change. Even the most stringent mitigation efforts cannot avoid further impacts of climate change in the next few decades, which makes adaptation essential. On the other hand, unmitigated climate change would in the long-term exceed the capacity of natural and human systems to adapt.

Second, societies have a long record of adapting to the impacts of weather and climate. In other words, adaptation is not a hypothetical concept. It is taking place now. Crop diversification, drought monitoring and flood protection are only some of the examples of proactive adaptation measures. Adaptation can also be reactive, for example, an urgency response, disaster recovery and even migration. Our ability to adapt proactively to current climate variability has increased significantly in recent decades, primarily due to the development of operational forecasts of El Niño and La Niña. NOAA and other agencies have been central to this process.

My third point is that climate change will also require responses that go beyond adapting to current climates. Climate change often poses novel risks outside the range of experience, for example, through accelerated glacier retreat and permafrost melt and changes in the intensity of heat waves and hurricanes. Even when the impacts of climate change are not yet evident, scenarios of future impacts may already be sufficient to justify some adaptation measures, particularly for long-lived infrastructure. Just to give one example, a sewage treatment facility on Deer Island in Boston Harbor was constructed in 1998 at a much higher elevation, taking into account anticipate sea-level rise. New York City meanwhile is considering scenarios of future changes in temperature, rainfall, sea-level rise and extreme events as part of its review of water supply options. Dr. Rosenzweig on this panel in fact is involved in these efforts.

My fourth point is that despite our experience and expertise, adaptation is not a slam dunk. There are substantial limits and barriers. Even rich countries have vulnerable populations. Hurricane Katrina is a prominent example but is not the only one. There were 15,000 excess deaths in less than a month in France in the 2003 heat wave. Further, demographic trends in social choices have in many cases resulted in maladaptation, and Dr. Burkett mentioned some of the cases. Even adaptations that have been put in place to reduce current risks such as levies could engender a false sense of complacency and exacerbate longer-term vulnerabilities if they do not incorporate the full range of risk possibilities in their design. Costs are another barrier. A recent estimate of the World Bank puts the global incremental annual costs of adaptation to climate change to be between $10 billion and $40 billion U.S. a year. Information on costs, however, remains very preliminary. We also lack usable information. Many adaptation decisions are very local at the level of households, farms, watersheds, infrastructure projects and cities where reliable climate scenarios are often lacking. Users also often need information on a whole range of climate-related variables, rainfall, dry spells, winds, snow cover, temperature and rainfall extremes, for their decisions and often such information is either not reliably predicted by climate models or not available. Even when information exists, access to it is not universal. Further, adaptation is often not a team sport. Actions by one person or a group can often compound the vulnerability of others.

My fifth and final point is that there is significant room for public policy on adaptation. Adaptation needs to be treated as a core component of a comprehensive plan of policy. To be effective, consideration of climate risks needs to be integrated within broader programs ranging from natural resource management to disaster reduction to international development assistance. Adaptation should not be pigeonholed as an issue just for climate policy. In many cases, climate change would require only tweaking of existing policies or better enforcement of existing regulations. Buy-in from regulatory agencies is therefore critical. In certain cases, climate change would require early actions, in particular, some of the impacts mentioned by Dr. Rosenzweig. For example, changes in snow cover, permafrost melt and so on are examples of climate change impacts occurring now where adaptation measures are needed. Adaptation to climate change is also needed for infrastructure decisions where decisions today might have a long-term lock-in. Government can also play a role in centralizing adaptation by private actors. In particular market mechanisms are still underutilized for adaptation. Finally, further efforts are also needed in the development of provision of usable knowledge for adaptation. This may require an integrated suite of climate information products ranging from climate monitoring to seasonal/interannual forecasts as well as projections for climate change.

Thank you.

[The prepared statement of Dr. Agrawala follows:]

PREPARED STATEMENT OF SHARDUL AGRAWALA[1]

Assessment of Adaptation Practices, Options, Constraints and Capacity: The 2007 IPCC Assessment

1. Introduction

Chairman Gordon, Ranking Member Hall, and other Members of the Committee. Thank you for the opportunity to communicate to you today on some of the recent findings of the IPCC Working Group II Fourth Assessment Report (AR4).

My name is Shardul Agrawala. I am a Visiting Senior Fellow in Science, Technology and Environmental Policy at the Woodrow Wilson School of Public and International Affairs at Princeton University. I am currently on sabbatical from the Organisation for Economic Co-operation and Development (OECD) in Paris, where I have led the work-program on Climate Change and Development for the past five years. I received my Ph.D. from Princeton University, and have previously worked on assessments of climate change and variability at Harvard and Columbia Universities. At the OECD, I work closely with our Member governments (which include the United States) on policies to better integrate consideration of climate risks in their international development assistance as well as their domestic policies. My publications include two recent books on adaptation to climate change, and another on assessing the benefits of climate policies. I was first involved with the Intergovernmental Panel on Climate Change (IPCC) in 1994–95 during the Second Assessment Report when I served as a Lead Author for Working Group II.

For the IPCC Fourth Assessment Report (AR4), I have had the honor to serve as the Co-ordinating Lead Author (CLA) for Working Group II Chapter 17, *Assessment of Adaptation Practices, Options, Constraints and Capacity,* and as a drafting author for the Technical and Policy-maker Summaries. My testimony today will summarize some of the main findings from IPCC Working Group II AR4 as they pertain to adaptation—primarily from Chapter 17, but I will first draw upon Chapter 18 to establish the interrelationships between adaptation and mitigation.

2. Adaptation to climate change is necessary, but not sufficient

Both mitigation and adaptation help to reduce the risks of climate change. Mitigation—through the reduction in sources or enhancement of sinks of greenhouse gases—reduces all impacts of climate change. Adaptation—through adjustments in human and natural systems to actual or expected climatic changes—can be selective. It can reduce negative impacts, and take advantage of the positive.

The costs of both mitigation and adaptation are predominantly local and near-term. Meanwhile, the climate related benefits of mitigation are predominantly global and long-term, but not immediate. Owing to lag times in the climate system, the benefits of current mitigation efforts will hardly be noticeable for several decades. The benefits of adaptation are more immediate, but primarily local, and over the short- to medium-term.

Given these differences between mitigation and adaptation, climate policy is not about making a choice between adapting to and mitigating climate change. Even the most stringent mitigation efforts cannot avoid further impacts of climate change in the next few decades, which makes adaptation essential, particularly in addressing near-term impacts. On the other hand, unmitigated climate change would, in the long-term exceed the capacity of natural, managed, and human systems to adapt.

3. Adaptation to climate change is occurring now, but on a limited basis

Societies have a long record of adapting to the impacts of weather and climate through changes in behavior, choices of technology and infrastructure, use of market instruments, and public policies. Crop diversification, weather and seasonal climate

[1] Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author and do not necessarily reflect those of Princeton University, the OECD or its Member governments.

forecasting, drought and hurricane early warning systems, flood protection, weather derivates, and establishment of coastal-setbacks are only a few examples of proactive adaptation measures. Adaptation can also be reactive, for example, emergency response, disaster recovery, and even migration.

The IPCC Fourth Assessment Report notes that significant advances have been made in the ability to adapt to seasonal to inter-annual climate variability. This has been due to the development of operational capability to forecast El Niño and La Niña events and their associated impacts. Institutions to produce seasonal forecasts have been established and mechanisms are now in place to facilitate the use of this information for anticipatory adaptation in agriculture, water resource management, food security, and other sectors. The U.S. Government, through NOAA and other agencies, has been central to this progress, not only in the domestic context but also in Latin America, Africa, and Asia.

The Fourth Assessment Report also concludes that climate change is likely to require forward looking investment and planning responses that go beyond responding to current climate. This is because climate change poses novel risks outside the range of experience, for example, through accelerated glacier retreat and permafrost melt, and changes in the intensity of heat waves and hurricanes. Countries ranging from Nepal to Switzerland are actively reducing risks of hazards associated with the expansion of glacial lakes and permafrost melt, as a result of rising temperatures. Even when the impacts of climate change are not yet discernible, scenarios of future impacts may already be of sufficient concern to justify adaptation responses into current planning. It may, for example, be cost effective to implement adaptation measures early on, particularly for long-lived infrastructure. For example, a sewage treatment facility on Deer Island in Boston harbor was constructed at a higher elevation, taking into account anticipated sea level rise. This was also the case for the Copenhagen Metro. There are, however, relatively few examples of such infrastructure projects at present.

Comprehensive strategies to adapt to climate change are also being put in place by a few countries, local governments, and international donors. Countries such as Finland, France and the UK are establishing national strategies and policy frameworks for adaptation, while donors ranging from the World Bank to the USAID are undertaking measures to climate-proof their development projects. At the local level, meanwhile, climate change scenarios are being considered by New York City as part of a review of its water supply system. Changes in temperature and precipitation, sea level rise, and extreme events have been examined and an eight step adaptation assessment procedure has been developed. Among the adaptation measures being examined are some that could be implemented relatively quickly, such as the tightening of water regulations in the event of an unusually severe drought. Also under examination are long-term infrastructure adaptations such as the construction of flood walls around low-lying wastewater treatment plants to protect against sea level rise and higher storm surges. Such examples, however, are still only "boutique" cases and remain fairly limited relative to the scale of the issue.

4. There are substantial limits and barriers to adaptation

Adaptation is not a slam dunk. For many parts of the developing world adaptation is constrained by the existence of low coping capacities and inadequate financial and technical resources to design and implement adaptation measures. However, even developed countries with high aggregate "adaptive capacity" have vulnerable populations, as was brought home by 15000 excess deaths in France during the 2003 heat wave and the devastation caused by Hurricane Katrina in this country in 2005.

There is also evidence that demographic trends and social choices in both developed and developing countries have, in many cases, resulted in maladaptation. For example, the conversion of coastal wetlands and the development of settlements and infrastructure may boost coastal economies but it also increases vulnerability of critical coastal systems to the impacts of current and future climate. Even measures that have been put in place to reduce current risks—such as levees and dams—could end up exacerbating longer-term vulnerabilities if they do not incorporate the full range of risk possibilities.

Adaptation could also entail significant costs. A recent estimate by the World Bank puts the global incremental annual costs to adapt to climate change to be between U.S. $10 billion to U.S. $40 billion. Information on costs and benefits of adaptation, however, remains very preliminary. Some regional and sectoral studies have identified adaptation measures that can be implemented at low cost or with high benefit/cost ratios. The precise estimates of costs and benefits, however, depend critically on the assumptions made. For example, whether investment in coastal protection is a better strategy than letting a particular coastal region be lost to rising sea levels depends upon assumptions about how real estate values would adjust as the coastal land gets submerged. Many of the adaptation cost estimates are also often in a narrow "engineering" sense and do not include the costs of implementation, or the social or economic externalities associated with putting such measures in place.

Adaptation is also constrained by significant gaps in the knowledge base required to undertake such actions. For example, climate information is frequently not available at the time and space scales, or for the specific climate variables, that are needed to inform decisions. Mean temperature—which is typically the variable that can be projected most reliably by climate models—is also often the least relevant for end-users. Users often need information on the likelihood of extremes for many operational decisions, which is often less reliable or not available at all. Even when information exists, individuals and groups may have different risk tolerance, as well as different preferences about whether and how to respond to such information. And even when actions are undertaken, the differential power and access to information and resources may promote adaptive responses by some, while constraining the ability of others to adapt.

5. Some Implications

Based on these findings from the Fourth Assessment Report I will conclude with a few personal recommendations.

Adaptation needs to be treated as a core component of a comprehensive climate policy. Consideration of the risks posed by climate change also need to be integrated within broader programs and budgetary processes, ranging from natural resource management, to disaster risk reduction, to international aid. In many cases, adaptation to climate change would require better enforcement or further strengthening of existing regulations. Buy-in from regulatory agencies is therefore critical.

Many adaptation actions will ultimately be undertaken by individuals, communities and private actors. However, the government can play an important role by promoting the development and provision of usable knowledge that would facilitate decisions by private actors. This may require an integrated suite of climate information products from climate monitoring, to seasonal/inter-annual as well as climate change projections. Continuing efforts are also needed to provide information on climate variables, and at the temporal and spatial scales in line with user needs. Proactive efforts might also be needed to ensure timely and equitable access to such information.

BIOGRAPHY FOR SHARDUL AGRAWALA

Dr. Shardul Agrawala is a Visiting Senior Fellow in Science, Technology and Environmental Policy at the Woodrow Wilson School of Public and International Affairs at Princeton University. He is currently on sabbatical from the Organisation for Economic Co-operation and Development (OECD) in Paris, where has led the work program on Climate Change and Development for the past five years.

Dr. Agrawala received his Ph.D. from Princeton University, and has previously worked on assessments of climate change and variability at Harvard and Columbia Universities. His publications include two recent books on adaptation to climate change, and another on assessing the benefits of climate policies. He was first involved with the Intergovernmental Panel on Climate Change (IPCC) in 1994–95 during the Second Assessment Report when I served as a Lead Author for a chapter Working Group II.

For the IPCC Fourth Assessment Report (AR4), Dr. Agrawala serves as the Coordinating Lead Author (CLA) for Working Group 11 Chapter 17, *Assessment of Adaptation Practices, Options, Constraints and Capacity,* and as a drafting author for the Technical and Policy-maker Summaries.

Chairman GORDON. Thank you.

Dr. Pulwarty, you are recognized for five minutes.

STATEMENT OF DR. ROGER S. PULWARTY, PROGRAM DIRECTOR, NATIONAL INTEGRATED DROUGHT INFORMATION SYSTEM (NIDIS), OFFICE OF OCEANIC AND ATMOSPHERIC RESEARCH, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, U.S. DEPARTMENT OF COMMERCE

Dr. PULWARTY. Good morning, Chairman Gordon, Mr. Ehlers and the other Members of the Committee. Thank you for this opportunity to speak to you about Working Group II of the IPCC.

My name is Roger Pulwarty. I am a physical scientist in the NOAA Oceanic and Atmospheric Research Climate Program Office and the program manager for the U.S. National Integrated Drought Information System, or NIDIS, that was mentioned by Mr. Hall this morning. I have the honor of serving as the Lead Author on Chapter 17, as you have heard, also contributing to Chapter 3 on *Freshwater Resources and Their Management,* a Lead Author on the forthcoming IPCC Special Report on *Climate Change and Water,* and the U.S. Climate Change Science Program Report on *Weather and Climate Extremes in a Changing Climate.*

The focus of my testimony is on the results of Chapter 17, especially as they relate to the United States and to water resources. Chapter 17 sought to address the following questions in the context of climate: what are our adaptation strategies, as you have heard, and how can they be implemented; what are the benefits, costs and limits of such adaptation strategies, and more importantly, what are in fact good adaptation practices.

The IPCC definition of climate change refers to any change in climate over time, whether due to natural variability or as a result of human activity. It is thus the goal of good adaptation strategies to take advantage of opportunities and to reduce the risks associated with variability and change. It is important to note that climate change could in the long-term exceed the capacity of particular natural and managed systems to adapt.

Climate change adaptation strategies will be important for various sectors of the U.S. economy and society and may be implemented in a number of ways. Some adaptation strategies and initiatives are infrastructure-based and may require major up-front investments. One example that you have heard about is the Deer Island sewage facility in Boston Harbor which, it should be noted, was completed in 1998. A more complex but potentially major mode of adaptation to climate change will involve shifts in land use, watershed, ecosystems and livelihoods. Adaptation strategies and practices in the United States have been observed in the insurance sector and are focused on property damage. As a result of climate change, demand for insurance products is expected to increase. At the same time, however, climate change effects could reduce insurability and threaten insurance schemes, possibly resulting in the States becoming the insurer of last resort. As we have seen in the aftermath of recent hurricane seasons such as 2004 and 2005, it can take only one major climatic event to set such changes into motion. Adaptation strategies and implementation initiatives in infrastructure, insurance, financial markets and collaborative resource management may be needed to address water availability and quality.

One critical area is the western United States. Projected warming in the western mountains of North America is very likely to cause decreased snowpack, more winter flooding due to earlier runoff, and reduced summer flows. These effects will exacerbate competition for already overallocated water resources. For example, in the case of Sacramento-Joaquin River and the Colorado River basin, stream flow changes projected beyond 2020 indicate that it may not be possible to fulfill water demands in those basins. If climate change results in greater water scarcity relative to demands, future adaptations will be necessary to address competition for water and may include improved water use efficiency and better demand management through metering, pricing and other mechanisms. We might also have to address institutional changes that improve the tradability of water rights while securing water for the environmental services that we depend upon. Voluntary water transfers including short-term water leasing, the permanent sale of water rights from agricultural to urban and environmental uses are becoming increasingly common in our western States. In California, adaptive management measures include water conservation, reclamation and the combined use of surface and groundwater and the desalination of brackish water. These have all been advocated as means of proactively responding to water scarcity. It takes time to fully implement such changes so adaptations such as these are likely to become more effective as we learn and time passes.

A major barrier to implementing adaptive measures in the United States is that adaptation is not currently a high priority. Many adaptation strategies can be implemented at low cost. The comprehensive estimates of adaptation costs, benefits and the limitations of the practices themselves are currently lacking. Coping with uncertainties associated with estimates of future climate change and the effects on economic and environmental resources means that we will have to adopt management strategies and measures that are robust enough to apply across a range of potential scenarios about the future. Adaptive capacity to manage climate changes can be increased by introducing adaptation measures into existing watershed, water sources, urban and coastal management plans and operations. One option based on experience is to develop research and management partnerships that provide decision-makers with credible, relevant and timely climate information and to improve the capacity to use such information for risk management. The IPCC report refers to such activities as mainstreaming. By doing so, adaptation to climate change will become part of other well-established programs to increase societal resilience and to increase national benefit.

I am happy to answer questions that the Members might have. Thank you.

[The prepared statement of Dr. Pulwarty follows:]

PREPARED STATEMENT OF ROGER S. PULWARTY

Chairman Gordon, Ranking Member Hall, and other Members of the Committee, thank you for the opportunity to speak with you today on the Working Group II report of the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report—'Climate Change 2007.'

My name is Roger Pulwarty. I am a Physical Scientist in the NOAA Office of Oceanic and Atmospheric Research Climate Program Office and the program manager for the U.S. National Integrated Drought Information System. As a contributor to the Intergovernmental Panel on Climate Change Working Group II, I have had the honor of serving as a lead author on Chapter 17, *Assessment of Adaptation Practices, Options, Constraints and Capacity,* and as a contributor to the Chapter 3, *Freshwater Resources and Their Management.* I am also a lead author on the forthcoming IPCC Special Report on *Climate Change and Water,* and on the author team for the U.S. Climate Change Science Program, Synthesis and Assessment Report on *Weather and Climate Extremes in a Changing Climate.* My role in the latter two reports focused on impact assessment and adaptation responses.

Working Group II was charged with assessing the scientific, technical, environmental, economic, and social aspects of vulnerability (sensitivity and adaptability) to climate change, and, the negative and positive consequences for ecological systems, socio-economic sectors, and human health. As you know, the report of Working Group I (released on February 2, 2007) covered physical climate science, while the Working Group III report will cover greenhouse gas mitigation. Chapter 17 of the Working Group II report focused on the following issues for different sectors (e.g., water, agriculture, biodiversity) and communities (coastal, island, etc.):

- The role of adaptation in reducing vulnerability and impacts,
- Assessment of adaptation capacity, options and constraints, and
- Enhancing adaptation practice and operations.

Given the expertise of my colleagues on this panel, I will focus my testimony on the results of Chapter 17, especially as they relate to water resources.

Chapter 17 sought to address the following questions in the context of climate variability and change:

- What are we adapting to?
- What are adaptation strategies?
- How can they be implemented?
- What are the benefits, costs and limits of such strategies?
- What are good adaptation practices?

The IPCC definition of climate change refers to any change in climate over time, whether due to natural variability or as a result of human activity. Climate and non-climatic factors can interact to produce opportunities or disaster. It is the goal of good adaptation practices to take advantage of such opportunities and to reduce associated risks. Climate variability and change influence events across timescales from a few hours or a season (e.g., floods and droughts) to year-to-year variability (e.g., El Niño-Southern Oscillation events). When changes in these types of events persist, decadal and longer-term trends also change. Adaptation strategies must therefore be engaged across all of these timescales.

Adaptive capacity is the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, take advantage of opportunities, or cope with the consequences. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, as well as the sensitivity and adaptive capacity of the system. Non-climactic factors are increasingly the most important influences on risk and thus, given a particular setting, even small climate changes can produce disproportionate impacts. It is not an either/or question as to whether the magnitude of societal impacts are a function of climate variability and change or of societal conditions alone. It is always a combination of both factors.

Adaptation to climate change occurs in the context of multiple stresses. Due to the inertia of the climate system, if emissions are reduced now, their effect in avoiding impacts by slowing the rate of temperature increase will not emerge until after several decades. Vulnerable populations, especially in the developing world and in poorer and elderly communities, have limited capacity to deal with climate shocks. Adaptation, therefore, will be important in coping with current climate vulnerabilities and early impacts in the near-term, and will help build resilient economies as our climate changes, regardless of how that change is derived. It is important to note that unmitigated climate change could, in the long-term, exceed the capacity of different natural, managed and human systems to adapt.

Examples of adaptation initiatives

Early examples where climate change scenarios have already been incorporated into infrastructure design to accommodate projected sea-level rise include the Confederation Bridge in Canada and the Deer Island sewage treatment plant in Boston harbor in the United States. The Confederation Bridge is a 13 kilometer bridge between Prince Edward Island and the Canadian mainland. The bridge provides a navigation channel for ocean-going vessels with vertical clearance of about 50 meters. Sea level rise was recognized as a principal concern during the design process and the bridge was built one meter higher than currently required to accommodate sea level rise from thermal expansion over its hundred year lifespan. In the case of the Deer Island sewage facility, the design called for raw sewage collected from communities onshore to be pumped under Boston harbor and then up to the treatment plant on Deer Island. After waste treatment, the effluent would be discharged into the harbor through a downhill pipe. Design engineers were concerned that sea level rise would necessitate the construction of a protective wall around the plant, which would then require installation of expensive pumping equipment to transport the effluent over the wall. To avoid such a future cost the designers decided to keep the treatment plant at a higher elevation, and the facility was completed in 1998.

There are several other examples of designers and engineers factoring particular aspects of climate change into their plans as projects have been undertaken around the world. These examples are primarily infrastructure-based adaptations requiring major upfront investments. A more complex, but potentially dominant mode of adaptation will be the potential for shifts in land use, ecosystems and livelihoods necessary to accommodate a new climatic regime.

To date, most adaptation practices have been observed in the insurance sector and have focused on property damage. Financial markets can internalize information on climate risks and help transfer adaptation and risk reduction incentives to communities and individuals while capital markets and transfer mechanisms can alleviate financial constraints to the implementation of adaptation measures. As a result of climate change, demand for insurance products is expected to increase, while at the same time climate change impacts could reduce insurability and threaten insurance schemes, possibly resulting in States being the insurer of last resort. While these market signals can play a role in transferring adaptation incentives to individuals, reduced insurance coverage can, at the same time, impose significant economic and social costs. Market signals have also fostered risk prevention through: (i) implementing and strengthening building standards; (ii) planning risk prevention measures and developing best practices, and (iii) raising awareness of policyholders and public authorities. In the longer-term, climate change may also induce insurers to adopt forward-looking pricing methods in order to maintain insurability.

Water availability and water demand in North America: What are the adaptation options?

Projected warming in the western mountains of North America is very likely to cause decreased snowpack, more winter flooding due to earlier runoff, and reduced summer flows, exacerbating competition for over-allocated water resources. In the case of the Sacramento-Joaquin River and the Colorado River basins in the Western United States, for example, streamflow changes projected beyond 2020 indicate that it may not be possible to fulfill all of the present-day water demands (including environmental targets), even with adapted reservoir management. By 2050 the Sacramento and Colorado River deltas could experience dramatic increases in salinity and subsequent ecosystem disruption.

If climate change results in greater water scarcity relative to demands, future adaptations may include technical changes that improve water use efficiency, demand management (e.g., through metering and pricing), and institutional changes that improve the tradability of water rights. If climate change affects water quality, adaptive strategies will have to be developed to protect the ensuing human uses, ecosystems and aquatic life uses. It takes time to fully implement such changes, so they are likely to become more effective as time passes. The availability of water for each type of use may be affected by other competing uses of the resource. Consequently a complete analysis of the effects of climate change on human water uses should consider cross-sector interactions, including the impacts of changes in water use efficiency and intentional transfers of the use of water from one sector to another. For example, voluntary water transfers (including short-term water leasing and permanent sales of water rights) from agricultural to urban or environmental uses are becoming increasingly common in the Western United States.

Increases in consumptive water use can reduce downstream areas of water supply that would have re-entered the stream as return flow. Such upstream uses could make irrigation infeasible in the lower reaches of basins that experience reduced streamflow. Thus the costs and consequences of adaptive mechanisms are as important as the adaptations themselves. It is important to ensure that emergency adjustments to events such as hurricanes, heat waves, and droughts do not increase vulnerability to longer-term changes. Thus increasing adaptive capacity in the near-term to manage climate changes as they occur becomes important.

Ensuring that present adaptation strategies also decrease long-term vulnerability by enhancing adaptation practice and operations under uncertainty:

Climate change poses a major conceptual challenge to resource managers, in addition to the challenges caused by population and land use change. For example it is no longer appropriate to assume that past hydrological conditions will continue into the future (the traditional assumption). Due to the uncertainty associated with climate change, managers cannot place confidence in single projections of the future. It will be difficult to detect a clear climate change effect within the next couple of decades, even with an underlying trend. The vast majority of published impact assessments have used only a small number of scenarios of the future. These have demonstrated that impacts vary among scenarios, although temperature-based impacts, such as changing in the timing of streamflows, tend to be more robust. The use of a scenarios-based approach to water management in the face of climate change is recommended, but poses two problems. First, the large range for different climate model-based temperature scenarios suggests that adaptive planning should not be based on only a few scenarios; there is no guarantee that the range simulated by the models represents the full range of temperatures that could be experienced. Second, it is difficult to evaluate the credibility of individual scenarios, and uncertainty injects additional complications. Based on the studies done so far, it is difficult to reliably predict the water-related consequences of climate policies and emission pathways. Adaptation procedures that do not rely on precise projections of changes in river discharge, groundwater, and other variables need to be developed. Consequently, research on methods of adaptation in the face of these uncertainties is needed. Whereas it is difficult to make concrete projections, it is known that hydrological characteristics will change in the future. Early warnings of changes in the physical system and of thresholds or critical points that affect management priorities become important. Water managers in some countries are already considering explicitly how to incorporate the potential effects of climate change into specific designs and multi-stakeholder settings. Integrated water resources and coastal zone management, are based around the concepts of flexibility and adaptability, using measures which can be easily altered or are robust to changing conditions. For example, in California adaptive management measures (including water conservation, reclamation, conjunctive use of surface and groundwater and desalination of brackish water) have been advocated as means of proactively responding to climate change threats on water supply. Similarly, resilient strategies for flood management and environmental restoration, such as allowing rivers to temporarily flood and reducing exposure to flood damage, might be preferable to or combined with traditional “resistance” (protection) strategies, such as in the Confederation Bridge case discussed above.

Adaptation procedures and decision support tools are important both in the context of present day climatic risks and for increasing societal resilience into the future. To develop the necessary procedures and tools requires continued scientific, technical and operational efforts. The focus of such efforts is on developing research and management partnerships that provide decision-makers and communities with credible, relevant information and the capacity to use such information effectively for climate risk management. Experience has shown that such knowledge and capacity is most effectively produced through:

- Enhancement of networks of systematic observations of key elements of physical, biological, managed and human systems affected by climate change particularly in regions where such networks have been identified as insufficient;
- Research into understanding and managing physical, biological and human systems where there is a risk of irreversible change due to climate and other stresses;
- Increased understanding of the potential costs and benefits of impacts due to various amounts of climate change, of damages avoided by different levels of emissions reduction, and of options for adapting to these impacts and managing the risks;
- Studies to explore how adapting to climate change and the pursuit of sustainable development can be complementary; and
- Learning-by-doing approaches, where the base of knowledge is enhanced through accumulation of practical experience.

Summary

Climate is one factor among many that produce changes in our environment. Demographic, socio-economic and technological changes may play a more important role in most time horizons and regions. In the 2050s, differences in the population projections of the four scenarios contained in the IPCC Special Report on Emission Scenarios show that population size could have a greater impact on people living in water-stressed river basins (defined as basins with per-capita water resources of less than 1000 m^3/year) than differences in emissions scenarios. As the number of people and attendant demands in already stressed river basins increase, even small changes in natural or anthropogenic climate can trigger large impacts on water resources.

Adaptation is unavoidable because climate is always varying even if changes in variability are amplified or dampened by anthropogenic warming. In the near-term, adaptation will be necessary to meet the challenge of impacts to which we are already committed. There are significant barriers to implementing adaptation in complex settings. These barriers include both the inability of natural systems to adapt at the rate and magnitude of climate change, as well as technological, financial, cognitive and behavioral, social and cultural constraints. There are also significant knowledge gaps for adaptation, as well as impediments to flows of knowledge and information relevant for decision-makers. In addition, the scale at which reliable information is produced (i.e., global) does not always match with what is needed for adaptation decisions (i.e., watershed and local). New planning processes are attempting to overcome these barriers at local, regional and national levels in both developing and developed countries.

The assessment in Chapter 17 leads to the following conclusions:

- **Adaptation to climate change is already taking place, but on a limited basis.**[1]
- **Adaptation measures are seldom undertaken in response to climate change alone.**[1]
- **Many adaptations can be implemented at low cost, but comprehensive estimates of adaptation costs and benefits are currently lacking.**[2]
- **Adaptive capacity is uneven across and within societies.**[1]

[1] = Very high confidence.

[2] = High confidence.

In the IPCC Summary for Policy-makers, the following terms have been used to express confidence in a statement: Very high confidence = At least a 9 out of 10 chance of being correct, High confidence = About an 8 out of 10 chance, Medium confidence = About a 5 out of 10 chance, Low confidence = About a 2 out of 10 chance, Very low confidence = Less than a 1 out of 10 chance.

Adaptive capacity to manage climate changes can be increased by introducing adaptation measures into development planning and operations (sometimes termed 'mainstreaming'). This can be achieved by including adaptation measures in land-use planning and infrastructure design, or by including measures to reduce vulnerability in existing disaster preparedness programs (such as introducing drought warning systems based on actual management needs).

The major barriers to implementing adaptive management measures are that adaptation to climate change is not as yet a high priority, and the validity of local manifestations of global climate change remains in question. Coping with the uncertainties associated with estimates of future climate change and the impacts on economic and environmental resources means we will have to adopt management measures that are robust enough to apply to a range of potential scenarios, some as yet undefined. Empirical research carried out since the IPCC Third Assessment Report (2001) has shown that there are rarely simple cause-effect relationships between climate change risks and the capacity to adapt. Adaptive capacity can vary over time and is affected by multiple processes of environmental and societal change as societies adjust from event (drought, flood, abrupt change) to event. Greenhouse gas mitigation is not enough to reduce climatic risks, nor does identifying the need for adaptations translate into actions that reduce vulnerability. By implementing mainstreaming initiatives, adaptation to climate change will become part of, or will be consistent with, other well-established programs to increase societal resilience, particularly environmental impacts assessments, adaptive management and sustainable development.

BIOGRAPHY FOR ROGER S. PULWARTY

Roger S. Pulwarty is a Physical Scientist at the U.S. Department of Commerce/NOAA/Office of Oceanic and Atmospheric Research Climate Program Office. He joined NOAA from the University of Colorado faculty in July 2006. Roger is the Program Director of the interagency and interstate National Integrated Drought Information System (NIDIS). He also leads the risk assessment component of the World Bank/NOAA project on "Mainstreaming Adaptation to Climate in the Caribbean." Roger holds a Ph.D. (1994) in Climatology from the University of Colorado, Boulder. From 1998–2002 Roger managed the NOAA/Regional Integrated Sciences and Assessments (RISA) Program.

Roger's research and applied interests have focused on, (1) social and environmental vulnerability to climate variability and change in the Americas; and (2) designing climate-related services to meet information needs in water resources, ecosystem and agricultural management in the United States. In addition to the National Research Council, Roger has served in advisory capacities to various federal and State agencies, the Glen/Grand Canyon Adaptive Management Program, and to the UNDP, UNEP, World Bank and the Organization of American States. He is a lead-author on the IPCC Fourth Assessment Report Working Group 2, the forthcoming IPCC Special Report on *Climate Change and Water,* and on the U.S. Climate Change Science Program Synthesis report on climate and weather extremes. Roger is Professor Adjunct at the University of Colorado, Boulder and the University of the West Indies. He is the co-editor of *Hurricanes: Climate and Societal Impacts* (Springer, 1997).

Chairman GORDON. Thank you, Doctor.

Dr. Schneider, you are recognized.

STATEMENT OF DR. STEPHEN H. SCHNEIDER, MELVIN AND JOAN LANE PROFESSOR FOR INTERDISCIPLINARY ENVIRONMENTAL STUDIES; PROFESSOR, DEPARTMENT OF BIOLOGICAL SCIENCES; SENIOR FELLOW, CENTER FOR ENVIRONMENTAL SCIENCE AND POLICY AT THE WOODS INSTITUTE FOR THE ENVIRONMENT, STANFORD UNIVERSITY

Dr. SCHNEIDER. Thank you very much, Congressman Gordon, distinguished Members. If you would indulge me in a short personal preference, for me, sitting here under the watchful eye of George Brown, reminding myself that 31 years ago as a 31-year-old I first testified to this committee, and at the time the issue was creating a national climate program office to deal with the fact that even then we were well aware that the use of the atmosphere as the recipient for tailpipe and smokestack emissions could well cause problems from the climate point of view. We were just becoming aware at the time that warming was emerging from cooling as the most likely event and clearly it was mostly theoretical projections forward for which we wanted to create the office.

If I had to summarize, as I am often forced to do in a media interview, so what is new in the last 31 years, I would argue that I guess it is that nature has been cooperating with theory and the projections of discernible change by the end of the century, increased heat waves, reduced cool waves and the further stress on things such as intensity of hurricanes would occur and did, ice would be shrinking, as we heard from Cynthia Rosenzweig and so forth. There has been a great breakthrough in our theoretical understanding since 31 years ago. It is that some of those concerns have become so manifest in the observational record that there is now a much larger constituency for paying serious attention to the problem, and I appreciate your interests in that.

So with that having been said, I have been the coordinating lead author with others of a summary chapter, Chapter 19 in the Working Group II report, which is the key vulnerabilities and the risks from climate change. Now, IPCC tends to be a rather arcane venture to many people with snippets in the press and I thought I would spend a minute of my time just giving you a little background on how we get to choose what we write about and what literature we assess. First I would say that we aren't simply librarians. It is not our job just to say what it is in the literature and there is so much, you can't put it all in anyway in an 800-page report. Our job is to assess what is relevant to the questions given to us by governments which are policy-relevant to them and to be sure that we provide clear statements of the credibility of the science so that confidence judgments can be made whether it is likely or speculative and so forth.

I guess the last thing you want after a long panel is lots of words, so I have highlighted in red the key words given our title of key vulnerability of our Plenary Agreed Outline. This is a negotiated document by the over 100 governments that meet and that give us a direction which all chapters are required to do, and I give you the example from my chapter. If you wanted to see it in detail, it is in my written submission. But just to highlight a few issues. In the front bullet, issues related to Article 2 of the U.N. Framework Convention on Climate Change. That is the one which said that nations are committed to prevent—to stabilize greenhouse gas concentrations in the atmosphere so as to prevent "dangerous anthropogenic interference with the climate system." We also were asked to identify key impacts and vulnerabilities, key risks for regions, stabilization strategies. We were asked in the context of impacts and vulnerabilities how could those vulnerabilities be reduced under at least the umbrella of stabilization and then finally, the last bullet is uncertainties and it is inconceivable when anybody is dealing with a system as complex not just as the climate system but the coupling, the interaction of climate systems and human systems that there wouldn't be substantial uncertainties, which is why we have confidence ratings.

One more point about uncertainties. Having been the coauthor of the Guidance Paper on Uncertainties for the previous assessment report, what we ask assessors to do and what has been done since is not just to state that there is uncertainty but to rank the components of the issues which are well established, and there are many, from the components of the issues with competing explanations from the components that are speculative. All too often they get lumped up in the media debate and create a cacophonous picture where people are confused. So the job of these assessment reports whether IPCC or the National Research Council, is to try to separate those out.

The next picture—well, I will just talk to it then—is that—well, okay. If the slide were showing—okay. What it would be showing is that in the process of identifying that, we can come up with a number of items that are "key vulnerabilities." The context was avoiding dangerous climate change and many governments said "Well, could you in Chapter 19 give us some guidance on avoiding dangerous climate?" and we said "No, of course we can't because the choice of dangerous is a value judgment about how you weigh risks of potential climate changes versus the risks of spending money that you want to use for other purposes. That is your job;" but what we can do is, we can give procedures whereby we can make it clearer what the tradeoffs are and what the criteria are for which people in the literature have identified things as key, and we came up with a list of seven criteria, and I will end with these: the magnitude of impacts, timing of impacts, persistence and reversibility of impacts, potential for adaptation, distributional aspects, meaning do rich get richer and poor get poorer or the other way around, likelihood, uncertainty is very important, and the importance of those systems, and no statement could be more of a value judgment than importance, and we explicitly stated that it is not the role of science to define or explain which vulnerabilities are key but it is our role to try to help to give criteria whereby stakeholders and decision-makers can be more ordered in their capacity to make their own judgments, and that is why the chapter lays that out. This was explicitly stated in the chapter. It is explicitly stated in the testimony though a little bit of it was removed from the summary for policy-makers but the important gist is still there.

Thank you very much.

Stephen H. Schneider*

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Testimony for

The House Committee on Science and Technology Hearing, "The State of Climate Change Science 2007: The Findings of the Fourth Assessment Report of IPCC Working Group II report, Climate Change Impacts, Adaptation, and Vulnerability."

10.00a.m., April 17, 2007
Room 2318, Rayburn House Office Building

*[Website for more info: www.climatechange.net.]

<u>IPCC Plenary Agreed Outline (PAO)</u>
<u>Chapter 19. Assessing Key Vulnerabilities and the Risk from Climate Change</u>
<u>Working Group II</u>
<u>Fourth Assessment Report</u>

- Methods and concepts: issues relating to Article 2 of the UNFCCC; reasons for concern; measuring damage; identifying key impacts and vulnerabilities, and their risk of occurrence
- Approaches to determining levels of climate change for key impacts
- Assessing key global risks
- Assessing key risks for regions and sectors
- Assessment of response strategies to avoid occurrence: stabilization scenarios; mitigation/adaptation strategies; avoiding irreversibilities; role of sustainable development; treatment of uncertainty
- Uncertainties, unknowns, priorities for research

Many of these impacts, vulnerabilities and risks merit particular attention by policy-makers due to characteristics that might make them *key*. The identification of potential key vulnerabilities is intended to provide guidance to decision-makers for identifying levels and rates of climate change that may be associated with "dangerous anthropogenic interference" (DAI) with the climate system, in the terminology of United Nations Framework Convention on Climate Change (UNFCCC) Article 2.

Ultimately, the definition of DAI cannot be based on scientific arguments alone, but involves other judgements informed by the state of scientific knowledge. No single metric can adequately describe the diversity of key vulnerabilities, nor determine their ranking. [19.1.1]

This chapter identifies seven criteria from the literature that may be used to identify key vulnerabilities, and then describes some potential key vulnerabilities identified using these criteria. The criteria are [19.2]:

-magnitude of impacts
-timing of impacts
-persistence and reversibility of impacts
-potential for adaptation
-distributional aspects of impacts and vulnerabilities
-likelihood (estimates of uncertainty) of impacts and vulnerabilities and confidence in those estimates
-importance of the system(s) at risk

General conclusions include [19.3]:

• Some observed key impacts have been at least partly attributed to anthropogenic climate change. Among these are increases in human mortality, loss of glaciers, and increases in the frequency and/or intensity of extreme events.

• Global mean temperature changes of up to 2°C above 1990-2000 levels would exacerbate current key impacts, such as those listed above (**), and trigger others, such as reduced food security in many low-latitude nations (*). At the same time, some systems such as global agricultural productivity, could benefit (o/*).

• Global mean temperature changes of 2 to 4 C above 1990-2000 levels would result in an increasing number of key impacts at all scales (**), such as widespread loss of biodiversity, decreasing global agricultural productivity and commitment to widespread deglaciation of Greenland (**) and West Antarctic (*) ice sheets.

• Global mean temperature changes greater than 4°C above 1990-2000 levels would lead to major increases in vulnerability (***), exceeding the adaptive capacity of many systems (***).

The "reasons for concern" identified in the TAR remain a viable framework to consider key vulnerabilities. Recent research has updated some of the findings from the TAR [19.3.7]:

• There is new and stronger evidence of observed impacts of climate change on unique and vulnerable systems (such as polar and high-mountain communities and ecosystems), with increasing levels of adverse impacts as temperatures increase (***).

• There is new evidence that observed climate change has likely already increased the risk of certain extreme events such as heat waves, and it is more likely than not that warming has contributed to intensification of some tropical cyclones with increasing levels of adverse impacts as temperatures increase (***).

• Distribution of impacts and vulnerabilities are still considered to be uneven, and low-latitude less-developed areas are generally at greatest risk due to both higher sensitivity and lower adaptive capacity, but there is new evidence that vulnerability to climate change is also highly variable within countries, including developed countries.

• There is some evidence that initial net market benefits from climate change will peak at a lower magnitude and sooner than was assumed for the TAR, and is likely that there will be higher damages for larger magnitudes of global mean temperature increases than estimated in the TAR.

• The literature offers more specific guidance on possible thresholds for initiating partial or near-complete deglaciation of Greenland and West Antarctica. There is less confidence since the TAR in assessments of the risk of abrupt, large scale changes to the Meridional Overturning Circulation (MOC).

Several conclusions appear robust across a diverse set of studies, in the integrated assessment and mitigation literature [19.4.2; 19.4.3]:

• Given the uncertainties in factors such as climate sensitivity, regional climate change, vulnerability to climate change, adaptive capacity and the likelihood of bringing such capacity to bear, a risk management framework emerges as a useful framework to address key vulnerabilities. However, the assignment of probabilities to specific key impacts is often very difficult due to the large uncertainties involved.

• Actions to mitigate climate change and reduce greenhouse gas emissions will reduce the risk associated with most key vulnerabilities. Postponement of such actions, in contrast, generally increases risks.

• Given the current atmospheric greenhouse gas concentrations (WG I SPM) and the range of projections for future climate change, some key impacts (e.g., loss of species, partial deglaciation of major ice sheets), cannot be avoided with high confidence. The probability of initiating some large-scale events is very likely to continue to increase as long as greenhouse gas concentrations and temperature continue to increase.

[The prepared statement of Dr. Schneider follows:]

PREPARED STATEMENT OF STEPHEN H. SCHNEIDER

I. Background of IPCC Assessment Process.

Assessment of the description, causes and implications of climate change is made on the basis of scientific analyses of a very complex coupled human-natural system requiring knowledge from physical, biological and social sciences, as well as the technology and the development communities. This implies that there will be a great deal of uncertainty in many elements of any such an assessment. Effective assessments try to separate out from the scientific literature and various often-contradictory claims from stakeholder groups the elements of scientific analysis that are well established, from those that are best characterized by competing explanations, from those that are more speculative. Given the complexities, it is often very difficult for non-specialists to sort out this ordered set of conclusions from established to speculative and thus governments have turned to assessment bodies to help with that process. In the U.S., for example, the National Research Council (NRC) has produced dozens of reports on climate change science and policy options that have important influence owing to their credibility, as each is heavily peer reviewed and produced by scientists known to be field leaders. However, national reports are less credible sometimes in other countries, and thus in the late 1980s governments set up an international assessment institution parallel to the NRC that would have a broad representation of disciplines, groups and nations.

The credibility of these Intergovernmental Panel on Climate Change (IPCC) assessments has generally been very high for similar reasons to the NRC reports: front rank scientists and others are joined together as Lead Authors, three rounds of reviews are undertaken, Lead Authors must justify their response to reviewers satisfactorily to a panel of about three Review Editors for each chapter, and governments approve line by line the Summary for Policy-makers (SPM) in a week-long Plenary at the end of the writing process—typically about three years. There are three working groups: Working Group 1 on the science of climate change and projections of its trends, Working Group 2 on the impacts of climate changes on environment and society and Working Group 3 on the policy implications. There is some overlap among topics mandated for each working group to address, and thus there are some Lead Authors in common in more than one report, as well as a Synthesis Report produced by lead authors from all working groups after the three more disciplinary working group reports are approved. The assessors are charged with addressing policy-relevant questions—such as the pros and cons of policy alternatives as expressed in the literature—as dictated in a government document (the Plenary-

Agreed Outline—PAO); but authors are asked to avoid being policy prescriptive—that is, expressing preferences on implementing any of the many options analyzed. In this testimony I will focus on the chapter I was a Coordinating Lead Author for:

IPCC Working Group II Fourth Assessment Report.

"Chapter 19, Assessing Key Vulnerabilities and the Risk from Climate Change."

II. Scope of Chapter 19.

The Plenary Agreed Outline (PAO) for Chapter 19 is as follows:

"*19. Assessing Key Vulnerabilities and the Risk from Climate Change*

- Methods and concepts: issues relating to Article 2 of the UNFCCC; reasons for concern; measuring damage; identifying key impacts and vulnerabilities, and their risk of occurrence
- Approaches to determining levels of climate change for key impacts
- Assessing key global risks
- Assessing key risks for regions and sectors
- Assessment of response strategies to avoid occurrence: stabilization scenarios; mitigation/adaptation strategies; avoiding irreversibilities; role of sustainable development; treatment of uncertainty
- Uncertainties, unknowns, priorities for research."

Therefore, our chapter addresses each of these topics by reviewing the literature and evaluating the state of the science. It is not simply a listing of the works in the literature that constitutes an assessment, but an evaluation of the confidence that the authors have in the quality of the science and its relevance for decision-makers. The latter is determined by both the PAO (at the outset) and by (in the middle of the writing process) reviews from experts and governments, as these reviews help Lead Authors to sort out what materials to include from the vast array of possibilities in the literature and to establish a consensus on the confidence in the state of the science or key conclusion. Since the title of Chapter 19 includes the word "Key," I will first explain how that PAO-required issue was addressed by the authors, drawing primarily from the text of the chapter. In the following, the square brackets with numbers in them are the sections of the semi-final draft of Chapter 19 where the detailed information on the topic can be obtained. After final consistency checking, the final chapter will be available on the IPCC Working Group II website about early May 2007.

III. Defining and Assessing What Is a "Key Vulnerability."

Climate change will lead to changes in geophysical, biological and socio-economic systems. An impact describes a specific change in a system caused by its exposure to climate change. Impacts may be judged to be harmful or beneficial. Vulnerability to climate change is the degree to which these systems are susceptible to, and unable to cope with, the adverse impacts. The concept of risk, which combines the magnitude of the impact with the probability of its occurrence, captures uncertainty in the underlying processes of climate change, exposure, impacts and adaptation. [19.1.1]

Many of these impacts, vulnerabilities and risks merit particular attention by policy-makers due to characteristics that might make them key. The identification of potential key vulnerabilities is intended to provide guidance to decision-makers for identifying levels and rates of climate change that may be associated with "dangerous anthropogenic interference" (DAI) with the climate system, in the terminology of United Nations Framework Convention on Climate Change (UNFCCC) Article 2. The precise language of Article 2—which the United States has signed and ratified—relevant to Chapter 19 is:

> "The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."

Ultimately, the definition of DAI cannot be based on scientific arguments alone, but involves other judgments informed by the state of scientific knowledge. No single metric can adequately describe the diversity of key vulnerabilities, nor determine their ranking. [19.1.1]

This chapter identifies seven criteria from the literature that may be used to identify key vulnerabilities, and then describes some potential key vulnerabilities identified using these criteria. The criteria are [19.2]:

— magnitude of impacts
— timing of impacts
— persistence and reversibility of impacts
— potential for adaptation
— distributional aspects of impacts and vulnerabilities
— likelihood (estimates of uncertainty) of impacts and vulnerabilities and confidence in those estimates
— importance of the system(s) at risk

Key vulnerabilities are associated with many climate-sensitive systems, including food supply, infrastructure, health, water resources, coastal systems, ecosystems, global biogeochemical cycles, ice sheets, and modes of oceanic and atmospheric circulation. [19.3]

In order to provide guidance to decision-makers on the kinds of impacts that many in the literature could consider "key," Chapter 19 prepared a synthetic summary table of representative key impacts, risks and vulnerabilities, as was required from our Plenary Agreed Outline. After many rounds of review and exchanges with authors in other chapters in all working groups, the following table has emerged. Confidence levels from the literature, other chapters, reviewers, and the Chapter 19 authors' scientific judgments are amalgamated and appear in the table with "o" implying low confidence (about 2 in 10 chance), "*" medium confidence (about a 5 in 10 chance of occurring), "**" high confidence (about an 8 in 10 chance of occurring) and "***" very high confidence (greater than 9 in 10 chance of occurring). That convention is used throughout the Working Group II Fourth Assessment Report (AR4). Table 19.1, the result of the process just described, follows:

Table 19.1: *Examples of potential key vulnerabilities. This list is not ordered by priority or severity but by category of systems, processes, or groups either affected or which cause vulnerability. Information is presented where available on how impacts may change at larger increases in global mean temperature (GMT). All increases in GMT are relative to circa 1990. Entries are necessarily brief to limit the size of the table, so further details, caveats and supporting evidence should be sought in the accompanying text, cross-references and in the primary scientific studies referenced in this and other chapters of the AR4. In many cases climate change impacts are marginal or synergistic on top of other existing and changing stresses. Confidence symbol legend: *** very high confidence, ** high confidence, * medium confidence, • low confidence. Sources in [-] are from chapters in the Fourth Assessment. Where no source is given, the entry represents conclusions of Chapter 19 authors.*

Systems, Processes, or Groups at Risk[Cross-references]	**Prime criteria for "key vulnerability" (from 7 criteria; 19.2) Short, descriptive words.**	**Relationship between temperature and risks (source to text) Temperature change by 2100 (above 1990-2000 levels)**					
		0°C	**1°C**	**2°C**	**3°C**	**4°C**	**5°C**
Global Social Systems							
Food Supply [19.3.2.2]	Distribution, Magnitude	Crop yield potential starts to dec at low latitudes* [5.2] Crop yield potential starts to inc at mid/high latitude* Global production potential likely to increase* [5.6]		Global production potential increases to around 3°C, * [5.6]		Yields of grain crops decline at mid/high lats * [5.2] Global production potential very likely to decrease above about 3 deg C* [5.6]	
Infrastructure [19.3.2]	Distribution, Magnitude, Timing	Damages likely to increase exponentially, sensitive to rate of climate change, change in extreme events, and adaptive capacity ** [3.5, 6.5.3, 7.5].					
Health [19.3.2]	Distribution, Magnitude, Timing, Irreversibility	Current effects are small but discernible * [1.3.7;8.4.1]		Although some risks would be reduced, aggregate health impacts would increase, particularly from malnutrition, diarrhoeal diseases, infectious diseases, floods and droughts, extreme heat, and other sources of risk */**. Sensitive to status of public health system ***. [8.ES, 8.3, 8.4, 8.6]			
Water Resources [19.3.2]	Distribution, Magnitude, Timing	Dec water availability and inc drought in some mid-lats and aemi-arid low lats ** [3.4, 3.7]		Severity of floods, droughts, erosion, water-quality deterioration will increase with increasing climate change ***. Sea level rise will extend areas of salinisation of groundwater, decreasing freshwater availability in coastal areas ***. [Ch 3 ES]. Hundreds of millions people would face reduced water supplies ** [3.4.3].			

Migration and Conflict	Distribution, Magnitude	Stresses such as increased drought, water shortages, and riverine and coastal flooding will affect many local and regional populations **. This will lead in some cases to relocation within or between countries, exacerbating conflicts and imposing migration pressures *. [19.2]	
Aggregate Market Impacts and Distribution	Magnitude, Distribution	Uncertain net benefits and greater likelihood of lower benefits or higher damages than in TAR o. Net market benefits in many high latitude areas; net market losses in many low latitude areas. * [20.6] Most people negatively affected o/*.	Net global negative market impacts increasing with higher temperatures * [20.6]. Most people negatively affected *.
Regional Systems			
Africa [19.3.3]	Distribution, Magnitude, Timing, Low Adaptive Capacity	Tens of millions of people at risk of increased water stress; increase spread of malaria*; [9.4.1, 9.4.4, 9.4.5]	Hundreds of millions of additional people at risk of increased water stress; increased risk of malaria in highlands; reductions in crop yields in many countries, harm to many ecosystems such as succulent Karoo * [9.4.1, 9.4.4, 9.4.5]
Asia [19.3.3]	Distribution, Magnitude, Timing, Low Adaptive Capacity	Over the temperature range, about 1 billion people would face risks from reduced agricultural production potential, reduced water supplies, or increases in extremes events * [14.4, 10]	
Latin America [19.3.3]	Magnitude, Irreversibility, Distribution, and Timing, Low Adaptive Capacity	Tens of millions of people at risk of water shortages •; [[13.ES, 13.4.3] many endemic species at risk from land use and climate change** (~1°C). [13.4.1, 13.4.2]	More than a hundred million of people at risk of water shortages ө * [13.ES, 13.4.3]; low lying coastal areas, many of which are heavily populated, at risk from sea level rise and more intense coastal storms * (about 2-3°C) [13.4.4]. Widespread loss of biodiversity, particularly in the Amazon *. [13.2, 13.4.1, 13.4.2].

Polar Regions [19.3.3]	Timing, Magnitude, Irreversibility, Distribution, Low Adaptive Capacity	Climate change is already having substantial impacts on societal and ecological systems **. [15.ES,]	Continued warming likely to lead to further loss of ice cover and permafrost ** [15.3]. Arctic ecosystems further threatened **, although net ecosystem productivity estimated to increase ** [15.2.2, 15.4.2]. While some economic opportunities will open up (*e.g.*, shipping), traditional ways of life will be disrupted ** [15.4].
Small Island States [19.3.3]	Irreversibility, Magnitude, Distribution, Low Adaptive Capacity	Many islands already experiencing some negative effects **. [16.2]	Coastal inundation and damage to infrastructure due to sea level rise** [16.4]
Indigenous, poor or isolated communities [19.3.3]	Irreversibility, Distribution, Timing, Low Adaptive Capacity.	Many of these communities are already stressed. ** [11.4; 14.2.3; 15.4.6]	Climate change and sea level rise adds to other stresses **. Communities in low-lying coastal and arid areas are especially threatened ** [6.4;3.4]
Drying in Mediterranean, western North America, southern Africa southern Australia, and north-eastern Brazil [19.3.3]	Distribution, Magnitude, Timing	Climate models generally project decreased precipitation in these regions [3.4.2, 3.5.1; 11.3.1]. Reduced runoff will exacerbate tight water supplies, decrease water quality, harm ecosystems, and result in decreased crop yields **. [3.4.2; 11.3.2]	
Inter tropical mountain glaciers; and impacts on high-mountain communities [19.3.3]	Magnitude, Timing, Persistence, Low Adaptive Capacity, Distribution,	Inter-tropical glaciers are melting and causing flooding in some areas, shifts in ecosystems are likely to cause water security problems due to decreased storage. [9.4.5, 10.4.4, 13.2.4, 19.3]	Accelerate reduction of inter-tropical mountain glaciers. Some of these systems will disappear in the next few decades *. [10.4.2, 13.ES, 13.2.4.1]
Global Biological Systems			

Terrestrial ecosystems and biodiversity [19.3.4]	Irreversibility, magnitude, low adaptive capacity, persistence, rate of change, confidence.	Many ecosystems already affected *** [1.3]	c. 20-30% species at inc. high risk of commitment to extinction* [4.4] Terrestrial biosphere tends towards a net carbon source*[4.4]	Major extinctions around the globe** [4.4] [>4oC]
Marine ecosystems and biodiversity [19.3.4]	Irreversibility, magnitude, low adaptive capacity, persistence, rate of change, confidence.	Increased coral bleaching** [4.4]	Most coral reefs bleached**[4.4]	Widespread coral mortality**[4.4]
Freshwater ecosystems [19.3.2.2]	Irreversibility Magnitude, persistence low adaptive capacity.	Some lakes already showing decreased fisheries output; pole-ward migration of aquatic species **. [1.3.4, 4.4.9]	Intensified hydrological cycles, more severe droughts and floods ***. [3.4.3]	Extinction of many freshwater species**, major changes in limnology of lakes**, increased salinity of inland lakes**.
Geophysical Systems				
Biogeochemical Cycles [WGII 4.4.9, 19.3.5.1; WGI 7.3.3.2.2, 7.3.3.2.3, 7.3.5, 7.4.1.2, 10.4.1, 10.4.2]	Magnitude, persistence, confidence, low adaptive capacity, rate of change.	Ocean acidification already occurring and increases as CO_2 concentration increases ***; ecological changes potentially severe * [1.3.4, 4.4.9]. Carbon cycle feedback increases projected CO_2 concentrations by 2100 by 20-220ppm for SRES A2, with associated additional warming of 0.1-1.5°C **. AR4 temperature range (1.0-6.3°C) accounts for this feedback from all scenarios and models but additional CO_2 and CH_4 releases possible from permafrost, peat lands, wetlands, and large stores of marine hydrates at high latitudes. [4.4.6, 15.4.2] * Permafrost already melting, and above feedbacks generally increase with climate change, but eustatic sea level rise likely to increase stability of clathrates. [1.3.1] ***		
Greenland ice sheet [WGII 6.3, 19.3.5.2; WGI 4.7.4, 6.4.3.3, 10.7.4.3, 10.7.4.4]	Magnitude, irreversibility, low adaptive capacity, confidence	Localized Deglaciation; (already observed, due to local warming); extent would increase with temperature *** [19.3.5]	Commitment to partial to near-total deglaciation *, 2-7[1] m sea level rise over centuries to millennia. [19.3.5]	Commitment to Near total deglaciation over centuries to millennia **[19.3.5]

[1] Range is based on a variety of methods including models and analysis of palaeo data [19.3.5.2]

West Antarctic ice sheet [WGII 6.3, 19.3.5.2; WGI 4.7.4, 6.4.3.3, 10.7.4.3, 10.7.4.4]	Magnitude, irreversibility, low adaptive capacity	Localized ice shelf loss and grounding line retreat *. (already observed, due to local warming) [1.3.1, 19.3.5]	Commitment to partial deglaciation, 1.5-5 m sea level rise over centuries to millennia. [19.3.5] */° Likelihood of near-total deglaciation increases with increases in temperature [19.3.5, 12.6] **
Meridional Overturning Circulation [WGII 19.3.5.3; WGI 8.7.2.1, 10.3.4]	Magnitude, persistence, distribution, timing, low adaptive capacity, confidence	Variations including regional weakening, (already observed but no trend identified)	Considerable Weakening **. Commitment to large-scale and persistent change including possible cooling in northern high latitude areas near Greenland and NW Europe °, highly dependent on rate of climate change. [19.3.5, 12.6]
Extreme Events			
Tropical Cyclone Intensity [WGI Table TS-4, observed 3.8.3, Q3.3, 9.5.3.6, projected Q10.1] [WGII 6.5.2, 7.5, 8.7, 11.4.5, 16.2.2, 19.3.6]	Magnitude, Timing, Distribution	Increase in Cat. 4-5 storms*/**, with impacts exacerbated by sea level rise	Further increase in tropical cyclone intensity */** exceeding infrastructure design criteria with large economic costs ** and many lives threatened **.
Flooding, both large–scale and flash floods [WGI, Table TS-4, 10.3.6.1, Q10.1, 14.4.1]	Timing, Magnitude	Increases in flash flooding in many regions due to increased rainfall intensity** and in floods in large basins in mid and high latitudes **.	Increased flooding in many regions (e.g., North America and Europe) due to greater increase in winter rainfall exacerbated by loss of winter snow storage **. Greater risk of dam burst in glacial mountain lakes **. [10.2.4.2]
Extreme Heat [WGI, Table TS-4, 10.3.6.2, Q10.1, 14.4.5]	Timing, Magnitude	Increased heat stress and heat waves, especially in continental areas ***.	Frequency of heat waves (according to current classification) will increase rapidly, causing increased mortality, crop failures, forest die-back and fire, and damage to ecosystems ***.
Drought [WGI Table TS-4, 10.3.6.1]	Magnitude, Timing	Drought already increasing * [1.3.3.2]. Increasing frequency and intensity of drought in mid-latitude continental areas projected ** [WGI 10.3.6.1].	Extreme drought increasing from 1% land area to 30% (A2 scenario) [WGI 10.3.6.1]. Mid-latitude regions affected by poleward migration of Annular Modes [WGI 10.3.5.5] seriously affected**.
Fire [WGI 7.3, WGII, 1.3.6]	Timing, Magnitude	Increased fire frequency and intensity in many areas, particularly where drought increases ** [4.2.1; 14.2.2].	Frequency and intensity likely to be greater, especially in boreal forests and dry peat lands after melting of permafrost ** [4.4.5; 11.3; 13.4.1, 14.4.2].

The table explicitly lists criteria used by the Lead Authors to select candidates for possible key vulnerabilities, as guidance to policy-makers on the process used. Chapter 19 authors do not advise which vulnerabilities or impacts are "more important," as that requires a value judgment and would be policy prescriptive. However, explicitly showing the criteria in each case for our selection of potential key vulnerabilities is intended to be helpful to stakeholders and policy-makers in their own evaluations of what they may consider "key." The Executive Summary of Chapter 19 summarizes the conclusions from Table 19.1 as follows:

General conclusions include [19.3]:

- Some observed key impacts have been at least partly attributed to anthropogenic climate change. Among these are increases in human mortality, loss of glaciers, and increases in the frequency and/or intensity of extreme events.
- Global mean temperature changes of up to 2°C above 1990–2000 levels would exacerbate current key impacts, such as those listed above (**), and trigger others, such as reduced food security in many low-latitude nations (*). At the same time, some systems such as global agricultural productivity, could benefit (o/*).
- Global mean temperature changes of 2 to 4 C above 1990–2000 levels would result in an increasing number of key impacts at all scales (**), such as widespread loss of biodiversity, decreasing global agricultural productivity and commitment to widespread deglaciation of Greenland (**) and West Antarctic (*) ice sheets.
- Global mean temperature changes greater than 4°C above 1990–2000 levels would lead to major increases in vulnerability (***), exceeding the adaptive capacity of many systems (***).
- Regions that are already at high risk from observed climate variability and climate change are more likely to be adversely affected in the near future due to projected changes in climate and increases in the magnitude and/or frequency of already-damaging extreme events.

IV. Reasons for Concern.

The "reasons for concern" identified in the TAR remain a viable framework to consider key vulnerabilities. Recent research has updated some of the findings from the TAR [19.3.7]:

- There is new and stronger evidence of observed impacts of climate change on unique and vulnerable systems (such as polar and high-mountain communities and ecosystems), with increasing levels of adverse impacts as temperatures increase (***).
- There is new evidence that observed climate change has likely already increased the risk of certain extreme events such as heat waves, and it is more likely than not that warming has contributed to intensification of some tropical cyclones with increasing levels of adverse impacts as temperatures increase (***).
- Distribution of impacts and vulnerabilities are still considered to be uneven, and low-latitude less-developed areas are generally at greatest risk due to both higher sensitivity and lower adaptive capacity, but there is new evidence that vulnerability to climate change is also highly variable within countries, including developed countries.
- There is some evidence that initial net market benefits from climate change will peak at a lower magnitude and sooner than was assumed for the TAR, and is likely that there will be higher damages for larger magnitudes of global mean temperature increases than estimated in the TAR.
- The literature offers more specific guidance on possible thresholds for initiating partial or near-complete deglaciation of Greenland and West Antarctica. There is less confidence since the TAR in assessments of the risk of abrupt, large scale changes to the Meridional Overturning Circulation (MOC).

V. The Potential Role of Adaptation.

Adaptation can significantly reduce many potentially dangerous impacts of climate change and reduce the risk of many key vulnerabilities. However, the technical, financial, and institutional capacity and the actual planning and implementation of effective adaptations is currently quite limited in many regions. In addition, the risk-reducing potential of planned adaptation is either very limited or very costly for some key vulnerabilities, such as loss of biodiversity, melting of mountain glaciers or disintegration of major ice sheets. [19.4.1]

A general conclusion on the basis of the present understanding is that for market and social systems there is considerable adaptation potential, but the economic costs are potentially large, largely unknown and unequally distributed, as is the adaptation potential itself. For biological and geophysical systems the adaptation potential is much less than in social and market systems. There is wide agreement that it will be much more difficult for both human and natural systems to adapt to larger magnitudes of global mean temperature change than to smaller ones, and that adaptation will be more difficult and/or costly for faster warming rates than slower rates. [19.4.1]

VI. Potential Robust Conclusions.

Several conclusions appear robust across a diverse set of studies, in the integrated assessment and mitigation literature [19.4.2; 19.4.3]:

- Given the uncertainties in factors such as climate sensitivity, regional climate change, vulnerability to climate change, adaptive capacity and the likelihood of bringing such capacity to bear, a risk management framework emerges as a useful framework to address key vulnerabilities. However, the assignment of probabilities to specific key impacts is often very difficult due to the large uncertainties involved.
- Actions to mitigate climate change and reduce greenhouse gas emissions will reduce the risk associated with most key vulnerabilities. Postponement of such actions, in contrast, generally increases risks.
- Given the current atmospheric greenhouse gas concentrations (WG I SPM) and the range of projections for future climate change, some key impacts (e.g., loss of species, partial deglaciation of major ice sheets), cannot be avoided with high confidence. The probability of initiating some large-scale events is very likely to continue to increase as long as greenhouse gas concentrations and temperature continue to increase.

BIOGRAPHY FOR STEPHEN H. SCHNEIDER

Dr. Stephen H. Schneider is the Melvin and Joan Lane Professor for Interdisciplinary Environmental Studies, Professor of Biological Sciences, and Professor (by courtesy) of Civil and Environmental Engineering. He is Co-Director of the Center for Environmental Science and Policy in the Freeman Spogli Institute for International Studies and a Senior Fellow in the Woods Institute for the Environment at Stanford University. Dr. Schneider received his Ph.D. in Mechanical Engineering and Plasma Physics from Columbia University in 1971. He studied the role of greenhouse gases and suspended particulate material on climate as a postdoctoral fellow at NASA's Goddard Institute for Space Studies. He was awarded a postdoctoral fellowship at the National Center for Atmospheric Research in 1972 and was a member of the scientific staff of NCAR from 1973–1996, where he co-founded the Climate Project.

Dr. Schneider focuses on climate change science, integrated assessment of ecological and economic impacts of human-induced climate change, and identifying viable climate policies and technological solutions. He has consulted with federal agencies and/or White House staff in the Nixon, Carter, Reagan, Clinton, and two Bush administrations.

Actively involved with the IPCC (Intergovernmental Panel on Climate Change), an initiative of the United Nations Environment Program and the World Meteorological Organization since its origin in 1988, he is currently a Coordinating Lead Author of Working Group II Chapter 19, *"Assessing Key Vulnerabilities and the Risk from Climate Change,"* as well as contributing to the Synthesis Report, which synthesizes the contributions of Working Groups I, II, and III, for the Fourth Assessment Report (AR4) to be published in 2007. AR4 will be used by governments worldwide as the definitive document regarding climate change science, impacts, adaptation, vulnerability, and mitigation until 2012.

In 1991, Dr. Schneider was awarded the American Association for the Advancement of Science/ Westinghouse Award for Public Understanding of Science and Technology for furthering public understanding of environmental science and its implications for public policy. In 1992, he was honored with a MacArthur Fellowship for his ability to integrate and interpret the results of global climate research through public lectures, classroom teaching, environmental assessment committees, media appearances, Congressional testimony and research collaboration with colleagues. Dr. Schneider was elected to membership in the U.S. National Academy of

Sciences in April 2002. He received the Edward T. Law Roe Award of the Society of Conservation Biology in 2003. He and his spouse-collaborator, Terry Root, jointly received the National Conservation Achievement Award from the National Wildlife Federation in 2003 and the Banksia Foundation's International Environmental Award in 2006 in Australia.

Dr. Schneider is founder and Editor of the interdisciplinary journal, Climate Change. Editor-in-Chief of the *Encyclopedia of Climate and Weather* and author of *The Genesis Strategy: Climate and Global Survival; Global Warming: Are We Entering the Greenhouse Century? and Laboratory Earth: The Planetary Gamble We Can't Afford to Lose.* In addition, he has authored or co-authored over 300 scientific papers, proceedings, legislative testimonies, edited books and book chapters, and some 115 book reviews, editorials and popularizations.

Dr. Schneider teaches undergraduate and graduate courses in Earth Systems, Human Biology, Civil Engineering, Biological Sciences, the Senior Honors Seminar in Environmental Science, Technology and Policy, and the Interdisciplinary Graduate Program in Environment and Resources, as well as guides the work of Ph.D. candidates, post-doctoral scholars, and other researchers.

Currently, Dr. Schneider is counseling policy-makers about the importance of using risk management strategies in climate-policy decision-making, given the uncertainties in future projections of global climate change. In addition to continuing to serve as an advisor to decision-makers, he consults with corporate executives and other stakeholders in industry and the nonprofit sectors regarding possible climate-related events and is actively engaged in improving public understanding of science and the environment through extensive media communication and public outreach.

DISCUSSION

DANGEROUS ANTHROPOGENIC INTERFERENCE

Chairman GORDON. Thank you, Dr. Schneider.

At this point we will have our questions, and I will open the questions with recognizing myself, the Chairman, for five minutes.

Could you put back up one of Dr. Schneider's exhibits, please? Any one of them would be fine.

Dr. Schneider, I noticed that there are some red and some black statements. How are those distinguished?

Dr. SCHNEIDER. Well, I put in red those things to call to the Committee's attention in short testimony. The identification of potential key vulnerabilities was designed to provide guidance to decision-makers on the levels and rates of climate change that might be associated with Dangerous Anthropogenic Interference, or DAI, which is exactly the terminology of the U.N. Framework Convention, and I will remind those here, some may not remember, back to 1992 at the Rio meeting that that was signed by President Bush at the time and ratified by the U.S. Senate, so this is in fact the law of the land and the second-most signed treaty, I believe, in world history. But the most important sentence is the one below that which is ultimately the definition of DAI, Dangerous Anthropogenic Interference, cannot be based on scientific arguments alone but involves other judgments informed by the state of scientific knowledge and that no single metric can adequately describe the diversity of these vulnerabilities nor determine the ranking. We got over 1,000 review comments and that was I think our most praised comment because we were open and forthright in saying that judgments have to be made by individual decision-makers on their own criteria and it is not our job to give you the answers.

POTENTIAL MITIGATION OF CLIMATE CHANGE

Chairman GORDON. Thank you, Dr. Schneider. Have we reached the point yet where scientists believe there is some impacts of climate change that cannot be aborted even with aggressive mitigation?

Dr. SCHNEIDER. Yes. I think that in Working Group I, it is very clear that the 0.75 degrees Celsius, something like 1.34 degrees Fahrenheit, warming since the Industrial Revolution, we can't roll that one back, and the probability that we will be able to hold the line on current emissions is very, very low, given world development patterns, and that we are committed to at least another degree or two of warming at best and at worst I believe their top number was 6.4 degrees by the 2090s.

CLIMATE CHANGE IMPACTS

Chairman GORDON. And the Pentagon released a study that discussed the possible security risks caused by climate change. What risks do you see associated with climate change?

Dr. SCHNEIDER. Well, I think that the risks as we stated in our chapter are those people already most vulnerable, which tend to be poorer people living in hot countries, people living in Hurricane Alley and high mountains where glaciers are melting, in the Arctic, Mediterranean, climates like California or the Mediterranean, they are the highest risk of natural climate variability, and if you add on top of that additional components of stress from human activities, they are the first groups to be feeling the effects. The only groups that would feel them even more severely would be natural systems species because they don't have the conscious adaptive capacity to put in irrigation systems to deal with their plight. They either can move or they can't, and those kinds of issues I believe are the ones that are most serious, and what the Pentagon was stressing is that in areas where human behavior and political situation have already created a stress situation, an additional stress on top of that could be a tipping point. I believe that was the sense in which they were concerned about climate on top of everything else.

ANTHROPOGENIC CAUSES OF CLIMATE CHANGE

Chairman GORDON. Thank you, Dr. Schneider. Let me just conclude with a question for everyone, and I want you to feel no qualms about disagreeing if I am not stating or summarizing the overall report. I am going to repeat to you what I got from it. Again, correct me I am wrong. I understand that we have observed evidence that global warming driven by human activities is having an actual impact on physical and biological systems. Is that true? A lot of vertical nods.

Dr. ROSENZWEIG. Yes, that is true.

Chairman GORDON. If you don't agree, please raise your hand because I want to get this on the record. The impacts are mixed, some beneficial and some negative, but without taking steps to adapt climate change and to mitigate greenhouse gas emissions, impacts will tend to be more negative than positive and this trend will get worse over time. We are going to experience climate change for several decades no matter what we do, but this assessment suggests that if we take action now to reduce greenhouse gas emissions, we can abort or at least delay more-severe impacts on climate change in the future. Is that true? All vertical nods. All right. So we need policies that promote both adaptation and mitigation. We need adaptation strategies to cope with current and near-term climate change impacts. We need mitigation strategies to adapt and to further future impacts so great that adaptation will not be sufficient to cope with the mitigation or with the magnitude of some projected changes. Have I gotten the thrust of this report correct?

Dr. SCHNEIDER. That is correct.

Chairman GORDON. Thank you very much. Again, thank you for your time, and I yield to Dr. Ehlers for five minutes.

Dr. SCHNEIDER. With that, Mr. Chairman, we wish we had you as a lead author on our report. It is very succinct and accurate.

Dr. ROSENZWEIG. Or in Brussels.

Mr. EHLERS. Thank you, Mr. Chairman. With that succinct summary, I am not sure we need to ask any more questions.

First of all, Dr. Pulwarty, your emphasis in your comments here was almost entirely on management——

Dr. PULWARTY. Yes.

Mr. EHLERS.—and adaptation. Does this mean you and the panel have basically given up on the hope of reining in CO_2 or methane emissions?

Dr. PULWARTY. No. The response is geared towards the chapters that we were actually tasked with writing. As was stated in the earlier comments, I think the combination of mitigation and adaptation is necessary. The management components become very important in the near-term because of the commitment that we already have in the system with CO_2—excessive CO_2 already in the atmosphere. So for us, it is not necessary a tradeoff but a two-pronged activity. One of the things that the adaptation focus helps us with is to imbed both natural climate variability and climate change in an integrated response to dealing with climatic risks. So both are still important and still equally important.

CLIMATE CHANGE IMPACTS: DROUGHT

Mr. EHLERS. Thank you.

Dr. Agrawala and Dr. Pulwarty both, you talked about, or the report predicts, that drought-affected areas will increase, and I am curious, what parts of the U.S. are vulnerable to this? I participated in a conference on this last year where I spoke and one of the authors suggested that if at current trends and some time in the next 50 or 75 years, Indiana would look like Texas, which is a horrible fate. I can say that since Mr. Hall has left. But is there any basis for that? Can we expect the great breadbasket of the world, the Midwest, to actually begin suffering from drought?

Dr. PULWARTY. One of the things we can definitely point to is a trend in drying within the Colorado River basin and that is very clear, and reduction in Great Lake levels as well. What I would like to do is ask Dr. Easterling, who focuses heavily on agriculture, if he would be willing to address your question.

Mr. EHLERS. Dr. Easterling?

Dr. EASTERLING. It is very clear from the accumulating evidence that the western third of the Nation dries, and if one look at an agriculturally meaningful quantity like runoff, that runoff projections under climate change out into the 21st century show a decline throughout most of the significant irrigated agricultural production areas of the country, especially the western Great Plains. I need not point out that we are already seeing declining groundwater levels just through normal irrigation water use and we would expect that to intensify under climate change.

Mr. EHLERS. When you say the western one-third, you are basically talking the Rockies westward, right?

Dr. EASTERLING. Well, if one looks at the numbers and of course they are never totally precise where you draw the boundaries but it appears to us that the Great Plains, western Great Plains would be involved in this general drying trend.

Mr. EHLERS. They are also facing exhaustion of the reservoir as well.

Dr. EASTERLING. Correct.

Mr. EHLERS. So if we own property in Nebraska or Kansas, we should sell.

Dr. EASTERLING. Or change to something else.

Mr. EHLERS. What about Indiana, the eastern Great Plains?

Dr. EASTERLING. Well, there may be opportunities to engage in irrigation in the middle or central to eastern parts of the Corn Belt but I think the studies are yet to have been done to give us compelling evidence that that is a viable option, increased irrigation in those areas.

CLIMATE CHANGE IMPACTS: THE GREAT LAKES

Mr. EHLERS. Thank you.

Dr. Burkett, you talked about coastal erosion issues and so forth and I agree with your concern there. I spent a few days on the eastern coast of the Chesapeake for a retreat recently and I was just astounded at how only a few feet rise would inundate that entire area. But being from the Great Lakes, I am concerned about how does all of this impact the Great Lakes in the United States? Someone mentioned earlier they had gone down. It is hard to know whether that is attributable to climate change or not. Do you anticipate any changes in the Great Lakes, the rainfall of course could affect it, but any other comments?

Dr. BURKETT. It was not included in our coastal chapter and I think perhaps Roger can answer that better than me.

Mr. EHLERS. Okay.

Dr. PULWARTY. One of the major issues regarding the Great Lakes has to do with increasing temperatures as it relates to evaporation, and so the link between temperature impact on snow that runs off into the Great Lakes and evaporation on the Great Lakes themselves are really where the signal for future lowering of lake levels is coming from.

Mr. EHLERS. All right. Thank you very much, Mr. Chairman.

Chairman GORDON. I noticed that Dr. Ehlers didn't ask if any State was going to wind up looking like Michigan.

Mr. EHLERS. There can be no equal.

Mr. GORDON. Dr. Baird is recognized.

CARBON SINKS

Mr. BAIRD. I thank the Chair. I thank our outstanding witnesses for their testimony.

Dr. Easterling, I come from a heavy forested State, and you talked predominantly about, as I followed your testimony about the impact of growth rates on agriculture. Can you talk a little bit about carbon sinking, particularly in forest products and the role that forests may or may not play as they sink for carbon. Did the group study that at all?

Dr. EASTERLING. That was peripherally considered partly because our chapter was really focusing on wood products and the productivity of the timber industry, but I will say that we would anticipate, based on our studies, in the early stages of the warming a positive effect on timber productivity in the higher latitudes. That would include of course the United States. And as the warming progresses out into the 21st century, that advantage to the higher latitudes grows stronger and we actually then begin to start to see the tropical latitudes lose advantage so that from a competitive standpoint, the higher latitudes and the timber industries may relatively be advantaged. Ipso facto, one would expect that as significant carbon sinks, particularly for young, managed forests, that we could see great potential for sequestering carbon. Of course, that potential will saturate at some point when we satisfy world demand for timber and any additional growth would be natural ecosystem growth and I am not qualified to comment on that part.

Mr. BAIRD. I appreciate that. One of the things we have been looking at in my region is what happens after a fire, and one option is to harvest the trees and sink the carbon in what we call houses. Another option is to leave the trees there to reburn and be eaten by bugs, et cetera, which will put more carbon into the air. In a rather ironic twist, the "environmental community" has opposed the harvesting of burned trees, preferring to leave them standing in a perfectly good woods, sit there and rot and decay and second-burn and produce all that carbon into the air. I kind of think it would be better to sink them myself and plant some new trees and grow a forest up, but that is a controversy for another day.

Dr. Rosenzweig, you look like you might have a comment on this.

Dr. ROSENZWEIG. I was just going to comment that observed effects of temperature increases already have shown alterations in disturbance regimens such as fire and pests, as you just mentioned, so temperature increases are already having an effect on mid-latitude and high-latitude forests.

IMPACTS ON THE FISHING INDUSTRY

Mr. BAIRD. We see larger and larger areas of acreage burn virtually every year. It is just a pretty steady increase and we see bug infestation, which some of us would also like to address, and again, I think there are significant carbon issues there and at some point I would be very interested if any of you have insights into somebody who might be able to give insights into the relative pros and cons of leaving burnt timber to stand or to harvest it and sink it, I would sure appreciate it.

None of you talked at all about—I know we have a limited-sized panel here but no one spoke about the impacts of fishing, which for our coastal and Michigan communities as well is pretty important. Any insights from the IPCC report on the impacts of fishing or aquaculture, commercial or recreational?

Dr. BURKETT. In terms of fishing impacts on coastal systems, most of the marine fisheries and coastal fisheries are estuarine-dependent, and tied to carbon export from the wetlands, particularly in the South Atlantic and Gulf regions. You know, that is what determines fisheries' productivity, and so as the wetlands go, as the coast goes, so goes the fisheries in general.

Mr. BAIRD. So the premise both on the nutrient and on the habitat and a rearing kind of situation, you might see a decline in there because you have lost the areas for saturation?

Dr. BURKETT. Right, and initially you might have a boost in productivity because of the declining material going into the estuary.

Ms. BAIRD. I see.

Dr. Pulwarty.

Dr. PULWARTY. There is also a related impact on in-stream temperature and decline of salmon and trout fishing and so on.

Mr. BAIRD. Dr. Schneider.

Dr. SCHNEIDER. Thank you. Some fish might be able to—the warm fish might be able to replace cold fish so it might not be easy for the grandfather to teach the grandchildren to fish precisely the same species. One hopes that at least there will be some replacement. But the one area where there seems to be greater concern, a little less relevant to the United States but certainly relevant to the world is the threat to coral reefs through a combination of increasing temperature and in fact that is one of the lowest thresholds, one to two degrees additional warming in Celsius leading to extensive bleaching beyond that extensive death of corals and those coral areas are a great breeding ground for fish of all kinds and that is further exacerbated if really do double and triple carbon dioxide. That makes the oceans more acidic, which would be a threat again to any calcite-shell creatures including corals. So that would have a significant impact on fisheries on a planetary scale, given the incredible importance of reefs as breeding sites.

Mr. BAIRD. Thank you, Dr. Schneider. I witnessed this personally some years ago, not that long ago, about five years ago, the Maldives Islands, where they had had, if I remember correctly, about a 90-degree—it is amazing to think of ocean temperature at 90 degrees for about three weeks long and it basically wiped out 90 percent of the coral and it was really tragic to see what was once magnificent coral zone basically looking like gray hulks of dusty debris.

Chairman GORDON. The gentleman's time has——

Dr. SCHNEIDER. I was just going to say that in fact that these are all part of a natural variability, El Niño and other such things, so people think well, it is normal and they will recover. The problem is when these fluctuations which can cause bleaching occur with a decreasing time between them, which is exactly what happens on the rising tide of overall warming, then what you do is, you don't give the reef enough time to recover naturally and that is precisely how global warming would interact with the natural variability and threaten those natural systems.

Chairman GORDON. The gentleman's time has expired. I understand that Chairman Boehlert took a group to the South Pole in his last term and they stopped at the Great Barrier Reef on the way and they saw firsthand, as reported to me, that it was very visible that that reef was dying.

Dr. Bartlett is recognized for five minutes.

ENERGY CONCERNS

Mr. BARTLETT. Thank you very much. Thank you for your testimony. The world faces a simultaneous interaction of two multi-decades-long tsunamis. One we have been talking about today, global warming, and the subsequent climate changes. The second is reflected in two articles that appeared recently. Just a few days ago in the *Wall Street Journal* was a front-page article that noted that the world's second-largest oil field, Canteral in Mexico, had declined in production 20 percent in the last two years. About three weeks ago, there was an article in the *Washington Post,* unfortunately not on the first page, where its importance should have placed it, which was talking about corn ethanol production. As you know, we produce relatively insignificant amounts of corn ethanol in terms of replacing gasoline but it has doubled the price of corn and tortillas are more expensive and Mexicans are hungry and my dairy farmers are going bankrupt because the price of feed for cows is up. This article noted that if we use all of our corn land for ethanol, we have fed no animals and no tortillas for us, and if you discounted that ethanol production for the contribution of fossil fuels, which the authors of the article said was 80 percent—I generally use 75 percent to be generous—that it would replace but 2.4 percent of our gasoline. That is all of our corn made into ethanol, and the authors noted that you could displace as much gasoline if you simply tuned up your car and put adequate air in the tires. These two articles of course are referring to the coming critical energy shortage in the world. Peak oil is a phenomenon which more and more folks are now focusing on, and of course, the shortage of these more readily available fossil fuels is going to result in increased use of coal, which in terms of the CO_2 production is really a very bad actor as you convert the coal to liquids and to gases.

Did you in any of your deliberations consider the simultaneous interaction of these two forces? I noticed one of your chapters dealt with adaptation practices, options, constraints and capacities. Did you just assume that we are going to have the present availability of energy? Isn't it very probable that the impacts of climate change are going to really be exacerbated by energy shortages and high prices? Yes, sir?

Dr. EASTERLING. To be sure, the issue of energy in agriculture and food production is huge and this was a growing concern. The rising prices for energy as we began the IPCC, it became very clear that as we looked out at the adaptation possibilities for food production that there would be this growing competition between food and energy, bioenergy. Although our task was not to analyze the energetics of bioenergy,. I will say that several of our authors have commented that it is not likely the energetics of using corn grain for ethanol will ever make sense and that as a placeholder for the use of cellulosic conversion to bioenergy. That is, using some grain but also using the other parts of the plant, the stover, plus also bringing into production woody products, wood chips, that makes eminent sense going forward but this is all outside of the central task of the IPCC. It will have to be a topic we consider in the next round.

Mr. BARTLETT. On the 14th day of next month will be the 50th anniversary of a speech given by Hyman Rickover at St. Paul of Minnesota to—one of you is nodding your head. You have read the speech. I would encourage you to do a Google search for Rickover and energy and that will pop up. You will find it a very revealing, very prophetic discussion. He suggested that competition for food and fuel would result in scarcities of food for people.

Thank you very much, Mr. Chairman.

Chairman GORDON. Thank you. The gentleman's time has expired.

Ms. Woolsey is recognized for five minutes.

INTERNATIONAL EFFORTS

Ms. WOOLSEY. Thank you, Mr. Chairman, and thank you to the witnesses. I would actually like to say that each one of these witnesses could be a hearing in and of and the topics in and of itself. Thank you.

Certainly we heard from all of you that global warming is a huge concern and I am hearing also, and I don't think that the Chairman asked you to nod your head on this, that it is not only a concern in the United States, it is a concern worldwide. Dr. Baird and I just returned—well, we spent the first week of the Easter break in China at a U.S./China relations conference and we started out in Shanghai where there is more high rises than any other city in the entire world and you can't breathe. I was struck by the development in China and the atmosphere and the environment. I took my all-American football player son with me. He got a nosebleed. My eyes got all red. We could not drink the water in the six-star hotel in our rooms. I mean, give me a break.

So in our conference I asked the question of the Chinese Government representatives the question of global warming and that discussion got going, and the Chinese Government representative's response was, well, the United States has used up, you know, more than their share with four percent of the population and 25 percent of the use of resources and probably equal amount of pollution, their share, now it is our turn. Well, of course that doesn't work, you know. There is no time for that turn and so of course we talked about that.

So my question to you is, where do you see the international effort, where is the United States' responsibility because we do have some making up to do? I mean, we certainly used more than our share, stressed natural systems, et cetera. A word you never used was "greed" and it all comes into play, and if you would like to respond, I would certainly like to hear it, of how much more can we do, how much does the international population world, what do we have to do and how fast do we need to be doing it?

Dr. SCHNEIDER. Well, I will take a shot at it, but this is not directly in the purview of the IPCC so I will respond personally. I have been a veteran of many, many such international meetings and I can report on what I have seen and how I interpret it for you in this connection. When you go to international meetings, typically the conference of the parties, you hear exactly what you said, Congresswoman Woolsey. You see blame. You will hear developed counties pointing out about corruption, lack of markets, insufficient development, overpopulation, pointing fingers toward the developing world and then you will hear from the developing world a legacy of colonialism, market share interference and an absolute greedy reluctance to give up any measure of your consumption. Of course, they are both right and the question is, if you are going to deal with the problem which is a commons problem where it is the collective integration of all of our individual actions, national, State and federal actions which create the problem, then we have to have cooperative solutions and cooperative solutions involve deals. They involve win-wins, and in the case of the international one, my view of that is, yes, we have a right to ask China and India not to hold the sustainability agenda of the planet hostage to their notion of the inequity of their development, but they also have a right to ask us to help them with that process since we are a factor of 10 per capita more consumptive than they are. So rather than blame, making deals where we get public-private partnerships with international backing to try to help invest our way out of it, not just here but also there, and then the ones who are cleverest enough in the invention also have partial ownership in the patents. You then start to be able to approach the problem but it is very difficult to have that kind of cooperation until people trust each other which is why it is so important to have international cooperation, and countries that created most of the problem, which unfortunately 80 percent of the emissions accumulated are from the 20 percent of the richest countries, we do have to take initial steps that will be stronger and more costly than other countries or we have no credibility. But your point is completely right. We can solve it together if and only if we can cooperate.

Ms. WOOLSEY. Dr. Rosenzweig.

Dr. ROSENZWEIG. I would like to comment on the IPCC scientists' part of this, that in the testimony that I read, one of our lead authors was a Chinese woman hydrologist, so the effects that I read about, the changes in the rivers, came directly from her and so I believe that working together as scientists is one way of establishing the cooperation that is needed to go forward on the issue.

Chairman GORDON. Thank you. The gentlelady's time has expired, unless somebody feels—Dr. Easterling?

Dr. EASTERLING. I wanted to respond just in the context of food security. The United States has been the supplier of last resort of food for decades and it is clear to us as I showed in the differences between the tropics and the mid-latitudes that there will have to be some movement of food across large areas through trade. I would not advocate a system of food aid per se but I think the U.S. will have an obligation to facilitate the relatively unrestricted movement of food and fibre into those regions that need it the most and to do it in a way in which the local farmers are not so disadvantaged by the trade that the internal capacity, the domestic capacity in African countries, for example, is not greatly diminished.

Chairman GORDON. The gentlelady's time has expired, and I will tell the gentlelady, we are looking at a hearing to go more into this specifically in the near future.

Dr. Gingrey is recognized.

ADAPTATION AND MITIGATION STRATEGIES

Mr. GINGREY. Mr. Chairman, I thank you. As I sit here and listen to this somewhat doomsday scenario, I turn to my friend on my right from California and I told him that not all is bad. One of these days maybe he will be surfing off the West Coast of Georgia. But I thought, Dr. Schneider, your response to Lynn Woolsey's question was the most succinct summary that I have heard in regard to this overall issue of science and policy, and although I don't think you get too many naysayers in regard to the science on this committee on either side of the aisle, either the Majority or the Minority Members, clearly at some point and some point soon we are going to have to address the science with sound policy. So that is why I am so appreciative, Dr. Schneider, of your remarks.

I want to address my question though to Dr. Agrawala, our friend from Paris by way of Princeton, because you talked about adaptation and I think a lot of your testimony dealt with that. It really seems to me that this Working Group II has spent a lot of time in the testimony of all six of you in regard to adaptation versus mitigation. I would like for you to maybe start with Dr. Agrawala in giving us some examples of how adaptation might work versus mitigation and what the relative cost-benefit ratio. I am thinking of course in terms of the early 19th century, or early 1900s, I should say, 20th century, when the automobile came along with Henry Ford, and what did people do with the horse and buggies. Well, clearly the Federal Government did not have to force them out of those horse and buggies. They adapted. It seems to me that, you know, there is great potential for adaptation. There is also need for some mitigation but striking that balance, so if you would address that for us, Doctor.

Dr. AGRAWALA. Thank you, Congressman. You are absolutely right. There is great potential for adaptation. I think one of the key messages from our chapter and indeed the entire Working Group II report is that we need both mitigation and adaptation. What we do in mitigation now will have impacts on the climate system only in several decades so there are a number of near-term impacts of climate change we already committed to and there is no option but to adapt to them. At the same time, adapting to unmitigated climate change over the long-term would be beyond the possibility of many systems, both natural systems and human systems. So we need a portfolio of responses which encompass both mitigation and adaptation. You are also right in saying that a lot of adaptation would happen autonomously. When people are faced with changes and different risks, they take a number of decisions, and our chapter actually documents a number of examples where a number of actors have taken observed changes in climate change as well as scenarios for future changes into account. There are examples, for example, of infrastructure projects. The Copenhagen Metro was built higher to take future sea-level rise into account. But at this time these examples are really boutique examples. You can literally document all the examples where future changes are taken into account in a couple of pages. And what we need to do is scale up these examples and have many more of them. The problem we run into is that even though there is wide familiarity with the seriousness of climate change and the impacts, we still don't have specific information for particular users to take those concerns into account when they make decisions. The questions from users are often, what is going to happen to my farm plot or my watershed or my city? We need information at that level of detail and that is one of the key issues I think where government policy and scientific research can play an important role.

Just a quick word about the costs. The costs of mitigation were not covered by the Working Group II report. The Working Group III report will be discussing this in a month's time. We did try to look at what we know about the costs of adaptation and our knowledge remains very limited. I gave you a range, which is nothing more than a back-of-envelope calculation by the World Bank saying that the total costs of adaptation globally could be between $10 and $40 billion per year. I wouldn't take those numbers to heart but it does show that there might be significant costs associated with it. We need a lot more research on this particular issue. Some of the research that has been done on cost has been on infrastructure adaptation, what would it cost to build a sea wall, for example, and that can be answered. But what has not been addressed is what are the costs of policies, what are the costs of implementation, and if it takes certain adaptation measures, what might be the spillover effects on other actors, and I think clearly a lot of work is needed before we can come to grips with this question.

Chairman GORDON. The gentleman's time has expired.

Mr. GINGREY. Thank you, Mr. Chairman.

Chairman GORDON. If you have something else, you need to go forward but otherwise——

Mr. GINGREY. No, Mr. Chairman, I am fine. I know one of the panel wanted to also weigh in but I am fine——

Chairman GORDON. Go right ahead.

Dr. ROSENZWEIG. I think it is important to realize that adaptation and mitigation are not always opposite. They are not always on opposite sides of the fence. There are actions that can do both. I will give two examples. In cities, having green roofs, vegetative roofs on cities, cool the people below in the buildings. That is an adaptation. At the same time, they reduce their air conditioning costs in the summer. That is a mitigation. So there can be synergies. One more from agriculture. Carbon sequestration in farmers' fields. This is mitigation in terms of sequestering the carbon, reducing atmospheric concentrations of carbon dioxide but, at the same time when we have higher organic matter in our farmers' fields, those farmers can then withstand both droughts and floods better. So while of course there are key issues to consider as we consider them separately, I think it is also important to realize that sometimes, and this is in the chapter, I believe—there was a chapter actually on adaptation and mitigation. There are times when they can be synergistic.

Chairman GORDON. Thank you. Dr. McNerney.

CLIMATE CHANGE IMPACTS: AGRICULTURE

Mr. MCNERNEY. Thank you, Mr. Chairman.

I would like to thank the panel for taking time to come up here and for your excellent and informative testimony. I have some detailed questions.

Dr. Easterling, what sort of—what are the sort of adaptations that you envision to prevent crop loss from occurring with rising temperatures? You mentioned that, and I wasn't sure what you were referring to exactly there.

Dr. EASTERLING. Well, one of the certainties we think of warming is that farmers will have the opportunity anywhere they grow their crops in this country to alter the planting dates to take advantage of the earlier spring warm-up. They can at the same time alter the types of crop varieties that they plant because not all crops are the same in terms of how long it takes for them to reach maturity, and there are some maturity classes that are able to handle the longer growing seasons that are likely to occur. In fact, we are already, as Dr. Rosenzweig noted in her chapter, starting to see increasing lengths of growing seasons, that these would be natural, easy-to-apply adaptations that no one would have to tell farmers how to do it.

CLIMATE CHANGE IMPACTS: WATER AVAILABILITY

Mr. MCNERNEY. Thank you. That doesn't sound that bad then.

There is a question for Dr. Pulwarty. I am from Northern California and much of the delta is in my district. You referred to the inability of the delta to provide the water that is required by about the year 2020. What specific mechanisms are involved in that in your mind? And you mentioned the partnership with water planners would help in adaptation. Could you give us some details?

Dr. PULWARTY. Certainty. From the basis of the last set of discussions that we have been hearing, there is investigated efficiency criteria in terms of how we use water that can actually be introduced. In many areas we have got more efficient technology for using water for irrigation. That does not reduce the quality of life in implementation. For the standpoint of the Sacramento-San Joaquin basin, one of the major signals that we are seeing there is increased early runoff of snow and a declining snowpack. That trend, given current rates of extraction of water and that trend in temperature, the estimates are that by 2020 the system and the Colorado River basin as well would not be able to meet its demands. So from the standpoint of adaptations and response, there are water banking mechanisms, water tradability and water rights for purchasing. The key question that is there is a lesson out of the drought of 1987 to 1992 in which a water bank was set up. It was a very successful water bank. But the place that the excess water for the bank came from was from the environment. We have to ask whether or not the adaptation mechanisms that we have are in fact viable under the conditions of the climate change and variability.

So we have learned to do some things better, there is no question about that, and water banking is one of them.

I do want to mention relative to that that in terms of efficient water technology, there is a huge emerging market in developing adaptation technology in which we could be engaged.

Mr. MCNERNEY. Thank you. I yield back.

Chairman GORDON. Thank you. I will now ask our panel to buckle up and recognize Mr. Rohrabacher for five minutes.

Mr. ROHRABACHER. Thank you very much, Mr. Chairman. Let me just note that it is really important that we have such discussions as today. However, let me lament that much of the discussion about global warming has been controlled and skewed in favor of alarmists' predictions. We have been, for example, treated to the predictions of gloom and doom that are based essentially on extending trend lines so far out that it becomes totally scientifically indefensible. You would say well, this trend over the number of years will mean in this—in another 150 years that this is what it is going to be. I would like to submit for the record an article by Richard Lindzen, who is a distinguished Professor at MIT. *[See Appendix 2: Additional Material for the Record.]* Unfortunately, this *Newsweek* article—I wouldn't even know about it if I was an American citizen because it made it into the international edition of *Newsweek* but didn't seem to make it into the national edition of *Newsweek*. In this article, he says there is no compelling evidence that the worrying trend seen will amount to anything close to the catastrophe being predicted. The Earth is always warming or cooling as much as 2/10 of a degree in a year and the periods of contrast of the average temperature are rare. Current alarm rests on the false assumption that not only are we living in the perfect world of temperatures but also that our warming forecasts for the year 2040 are somehow more realistic than the weatherman's forecast for next week. And let me note that this is a distinguished Professor from MIT. There are many such Professors who are totally dismissed, and as I say, this didn't make it into the American edition. I just happened to be flying back from Europe yesterday and I read this. In the same edition, there is an article about a study, Mr. Chairman, a very well-financed study that indicates that we should be chopping down all of the trees in the world in order to combat global warming. The effect of chopping every tree would actually, and this is a scientific study, that would actually then give us a cooler situation than if we left all the trees up. Now, again, I will submit for the record when I find it. I just have to look this up on the Internet.

There are also many quotes that I will put into the record at this point of highly respected scientists, and in terms of today's hearing we have a quote from Heindrich, and I don't know how to pronounce his last name——

Dr. SCHNEIDER. Tenecus.

Mr. ROHRABACHER. Yes, a former Director of Research for the Royal Dutch Meteorological Institute and Professor of Aeronautical Engineering at Penn State in which he states, "I protect the overwhelming pressure to adhere to the climate change dogma promoted by the adherence of the IPCC." So let us get a little of this on the record as part of the discussion. I think it is really important for us to have an honest and a broad-ranging discussion rather than a controlled discussion of this issue. The last time we had a hearing and I mentioned that perhaps dinosaur flatulence must have caused the first cycle of global warming, totally in jest, actually making fun of the position. People say we can control animal flatulence today and that is the way we are going to prevent global warming. In fact, it was widely reported in the press that I was serious about that, which indicates the people reporting it, controlling the public discussion are either dishonest or incompetent.

So with that, let me ask a couple questions of this panel. You know, it was really cold when I landed here. It was cold, and I was wondering, in recent years has it been getting warmer or colder, the last five, six years? What is the temperature? Should I pull out somebody else to tell you that the studies are indicating that it is actually getting cooler in the last six or seven years.

Chairman GORDON. I think the panel can answer that by repeating what 113 countries including the United States said at the last IPCC report. Would any member of the panel like to do that?

Mr. ROHRABACHER. Is it getting warmer or cooler in the last five years?

Dr. SCHNEIDER. On a global scale, it is harder to see a trend in five years.

Mr. ROHRABACHER. I didn't ask about the trend. I said, is it getting warmer or cooler?

Dr. SCHNEIDER. No climate scientist would discuss climate in a time frame much less than many decades so therefore we wouldn't look at what happens in five years, we would look at it over a period of——

Mr. ROHRABACHER. So I take it, it is getting cooler?

Dr. SCHNEIDER. I think it is irrelevant.

Mr. ROHRABACHER. Sir, I take it from your answer it is getting cooler because every time I ask a pointed question that seems to go in the other direction, we get this, you know, juggling act of trying not to answer the question. Let me note that even on the chart that I have been presented by the so-called experts, we see that the global warming of 1.5 degrees has taken place over 150 years starting in 1850. Let us also note that 1850 reflects something else. It reflects the bottom end of a 300-year decline in the Earth's temperatures by these very same people who have tried to reach out to find out what the temperature was in the past or what it would be in the future. You don't start off a trend line at the very bottom of a decline and say that this is the average that we are going to face into the hundreds of years in the future. Well, a lot of things like this that tend to let me not to suggest that there isn't some warming going on because there obviously is warming going on. The question is whether it is man-made is another question now that we know that NASA has given us reports of the warming that is taking place on Mars and other planets. That would suggest to me that if there is some warming, it may be due to sunspots more than it does to human activity. And if human activity ends up trying to control our lives, it will be in a way that prevents industrialization, et cetera. We are going to pay a severe price for this type of alarmism. One last question, if I could get it out here, is about these predictions and I guess I should just leave it at that.

Chairman GORDON. Well, the gentleman's time more than went over but I thought that it was important to let the minority of the Minority get its point on the record.

Mr. ROHRABACHER. A lot of minorities turn out to be right in the end, right?

Chairman GORDON. It makes us all think, so we thank you for that, and the gentleman from Louisiana, Mr. Melancon, is recognized for five minutes.

CLIMATE CHANGE IMPACTS: COASTAL LOUISIANA

Mr. MELANCON. Thank you, Mr. Chairman. I appreciate it. I guess one of the things that I feel needs to be pointed out, it is not just global warming but it is climate change that is occurring and it is a combination of factors and I don't think we are talking extremism. I think we are talking about adaptation and mitigation and we ought to be making deals to get this thing moving in the right direction. I have got a grandson so I have got a new vested interest. I have children too and don't know if I will ever see my great-grandchildren but I grew up in the south Louisiana marshes, which Ms. Vansickel is extremely aware of and is cognizant of the importance of it to this entire nation and not just Louisiana. I hope that whatever we do in the Congress will leave that estuary, that great area of this country, which most people aren't aware of, whole and back to where it should be so that America can benefit from it. So I am going to concentrate I guess on the coastal areas, the restoration, the rising sea levels and such.

Dr. Burkett, one of your key policy-relevant findings states that the coastal wetlands ecosystem such as salt marshes are especially threatened where they are sediment-starved or constrained. Would this assessment apply to coastal Louisiana?

Dr. BURKETT. Yes. Coastal Louisiana is one of those large mega deltas that is extremely vulnerable. Do you know that all these deltas around the world now off the coast of Vietnam or the Nile delta or in Shanghai, these deltas were formed during the past 7,000 years when sea-level rise was relatively miniscule, very small. They are all very vulnerable to even slight increases in the rate of sea-level rise, which is very likely to increase during this coming century so the Louisiana coast is just quite vulnerable. That is why it is listed as a hot spot of vulnerability. That said though, a lot of the coast can keep pace with sea-level rise even if it doubles if you can get the freshwater and the sediment to that marsh so that it can increase vertically in place. So it is not a hopeless situation.

Mr. MELANCON. And I guess that brings me exactly where I hoped you would go with it. The influence of human development and activities along the coast and adjacent watersheds and the Army Corps of Engineers through the years since 1927 when we decided we needed to harness or keep within the levies the Mississippi River while facilitating navigation, we have contributed to the living conditions by accelerating salt compaction along the coast. So what has man—and I refer to it, when people ask me why doesn't the Congress understand what is going on down here, I tell them that, you know, the Corps is partly at fault but so is the Congress in the United States because all these years we have been funding wants and concerns of the Mississippi River with the locks and dams and the other structures. Has that manmade situation along the Mississippi River which there is everything from the Allegheny and the Appalachians all the way to the Rockies and everything in between, Louisiana is the final resting spot for everything, for the good, for the bad, and has that harnessing of that river and channeling of that river caused the severe problems that we are experiencing in coastal Louisiana?

Dr. BURKETT. It is the most significant cause of wetland loss in Louisiana. There are over 300 dams and reservoirs along the Mississippi River drainage that prevent the sediment and freshwater from getting into the river and then it is being levied all way from Caro, Illinois, down to Venice, Louisiana, and so the seasonal overbank flooding that would be required to sustain those wetlands, especially in the light of accelerated sea-level rise, the ability of that river to maintain that delta, we have a riverless delta basically because of the human influence along the river.

Mr. MELANCON. Yeah, and then there are some people that don't believe that there is a hypoxia zone down there, and had we had been through the years taking the material that we are just summarily putting into the current and let run off the Outer Continental Shelf forming this hypoxia zone, which is of course the nutrients and whatever that is coming from the farmlands all through the Midwest and northern United States—would it help us at all if we were able to capture that sediment and with the help of our government get that sediment back out into the marshes and does that material in effect become a nutrient for the marshes where there is hypoxia in the Gulf?

Dr. BURKETT. It would. You have got 120 million tons of sediment just slipping past New Orleans every year out off the edge of the Outer Continental Shelf due to flood control works basically not for the benefit of Louisiana as much as up the river. So, you know, getting that sediment out into the marsh would counteract these changes that we are talking about, the accelerated sea-level rise and the increase in storm intensity that will have a dramatic effect on low-lying coastal wetlands like Louisiana's.

Mr. MELANCON. One of the things that of course I guess I experience some frustration here is that the relevance of the marshes to protect our inland cities, for instance, New Orleans. There are some people that appear to think that New Orleans is expendable but I go back to when the French took New Orleans and why it was taken and why America wanted it is because it controlled this country's mid-section and all the commerce, and to this day it still does, and the importance of that city, while it may not be expressed in national revenue, which I think we could document it does, without these coastal wetlands out there as the buffer, we are the first that get the problems from the rising elevation of sea level. But I think is it fair to say that in generations to come all America, particularly the south central part of—the south and center part of the American states need to be aware that it won't take long in terms of my lifetime before we start seeing a real problem for the center part of this country and along the Gulf Coast in particular?

Dr. BURKETT. Not just because of transportation down the river but also because of the energy development off the coast there. As you know, we have got about 3,600 oil and gas platforms off the

Louisiana coast. All that product comes onshore. The loop offshore terminal, you know, that product comes onshore. Two-third of this country's imported oil comes through those coastal facilities and they were all built for shallow—in shallow waters in a low-energy environment protected by barrier islands but the barrier islands, as I showed, you know, they are decreasing and so it is going to have an impact not just in Louisiana. It will affect our country and internationally.

Chairman GORDON. The gentleman's time has expired.

Mr. MELANCON. Thank you, sir.

Chairman GORDON. You know, my grandfather used to say the most important road in the county is the one in front of your house, and I think what we are starting to see is that this discussion is moving from the hypothetical to the specific which it is unfortunate for the country but it is probably better for the continuing discussion.

The gentleman from California, Mr. Bilbray, is recognized and then Mr. Inglis will be recognized.

AIR INDEXING IN THIRD WORLD COUNTRIES

Mr. BILBRAY. Thank you, Mr. Chairman. I assure the gentleman from Louisiana, short of basically eliminating the levies on the west bank, you know, we are just going to have to address the fact that Algiers is protected from floods and places like Houma and Bayou D'Arbonne have been protected for 100 years. And that protection actually has created a lot of the problem, and I wouldn't want to have to be the representative in that area having to address that issue—and I have been down there at town hall meetings in Billy Tauzin's old district and try to tell them that yeah, we are going to be removing the west bank levies because we need to use that to replenish your shoreline but that may be. A lot of those areas have been protected from inundation and that inundation is what over the centuries actually built it up and you are in a real catch-22 and I appreciate that. My wife is from New Orleans so I spent a lot of time there. My father is from that part of the world.

Mr. Chairman, can we ask the Committee—I mean the panel, I come from a background of air resources board from California. I did the air plan for Mexico City, and one of the things that I really run into is, how do we do the air indexing in Third World countries? When you talk about the percentage of First World country emissions and then Third World, you know, so often in my 20 years—18 years of working on clean air stuff, it was like, if it is not reported, it doesn't exist. How do we do an index for a Third World country? How do you determine emissions from countries that do not have true air indexing systems? Anybody know?

Dr. SCHNEIDER. In terms of local air pollution, I can't answer that question. In terms of trying to estimate the global emissions of greenhouse gases, there certainly are many international institutions which try to collect that data and there is always a debate at the margin as to whether the official data represents the actual data. There has been that argument in China about unreported coal burning, for example. But most of the colleagues I have—I don't myself do this work, but I have heard many talks on it. Most of them who do it believe that they think they are accurate 20 percent over time.

Mr. BILBRAY. Satellite photos using how much slash and burn is going on and estimate how much—how many tons are being emitted per acre or hector?

Dr. SCHNEIDER. There are a variety of techniques that people use including talking to people locally but you are correct that the data is not perfect. It is certainly accurate I would guess at the planetary scale to tenths of percent.

Mr. BILBRAY. Let me just tell you——

Chairman GORDON. I would suggest that is one reason we are trying to get NPOESS up and with those sensors can be helpful in this regard and it is important that we clean that program up and get it working if we want to get that good information.

Mr. BILBRAY. The gross deficiency in the estimate of emissions have all been a bigger problem than anybody is willing to admit for a long time. The evaporative emissions in California, which has the best air index in the world, was underestimated by 85 percent. I want to congratulate whoever is brave enough to stand up and say corn ethanol is, you know, the equivalent of an environmental Jimmy Swaggart. The fact of claiming that you are helping the environment by doing what we are doing with corn ethanol, I just think that we have just got to start saying the emperor has no clothes on this issue. And in California, we have run into this problem of you don't do, or say, anything against corn ethanol.

GLOBAL DIMMING

But getting back, is anybody here able to comment on an issue that is going to be essential for us? Because this panel is going to have to develop strategies and techniques of how to address this issue, and if we do not have the proper information going into the process, what comes out is not going to solve the problem. It may actually make the problem worse. And I would just like to say, has anybody here got a handle on this global dimming? Because you have got to understand, that may totally change our implementation strategy if it is enough of an issue to justify, you know, a scientific review and a policy change. Anybody got a comment on global dimming right now?

Dr. SCHNEIDER. Okay, I will try that again. Since the beginning of my career, I was weighing the global dimming associated with hazes around the atmosphere against the warming from greenhouse gases and we made the initial assumption that the hazes, the dimming was global. In fact, if the dimming were global, it would be a larger cooling effect than the greenhouse gases. What we discovered shortly thereafter, and I was proud to publish before I got attacked, was that only about a sixth of the world was really experiencing very large increases in these hazes, due to the industrial areas and the biomass burning. I think that the problem you have is that the direct effects of the dimming, that means between the clouds when radiation comes in and it is reflected back out to space and causes a slight cooling, is well understood. What is not well understood, and this is very clear in IPCC work in Group I, is that dust particles are the centers upon which droplets in clouds condense, and clouds are the primary reflectors of solar energy.

This is what we call indirect effect. And the indirect effect could be quite significant and in fact, one of the reasons you see IPCC tell you 1 degree to 6 degrees C, which is an incredibly large range of uncertainty in warming to 2090, about half of that is due to the uncertainty in how the clouds and the reflectivity will change. So that is real. What we don't know is exactly in which direction because soot particles are dark and can cause the climate to warm if they get into clouds and cause them to evaporate. They would enhance warming. If they actually increased the number of drops, they can enhance cooling. And that is why you will find that most honest scientific assessments, and most are, talk in ranges and bell curves because of the issues you raised still remaining not entirely resolved.

Chairman GORDON. The gentleman's time expires.

Ms. Giffords is recognized to learn more about the report's impact on Arizona.

CLIMATE CHANGE IMPACTS: SOUTHERN ARIZONA

Ms. GIFFORDS. Thank you, Mr. Chairman. Let us assume that we keep doing business as usual. I do represent Southern Arizona. I am very proud of that area of the country. But two weeks ago, right before the recess, I was able to co-host Dr. John Overpeck from the University of Arizona, who is a climatologist and one of the authors of the first IPCC report. So I am curious if this panel will address if we continue to do business as usual, we don't take any steps, what is going to happen to the West, particularly Southern Arizona, in terms of water resources, in terms of our forests, also possible changes in terms of immigration with a border country like Mexico, invasive species wildlife and human health?

Dr. PULWARTY. I will take that. One of the major things that we are seeing in terms of the projections, as I mentioned, is in terms of decline of water resources within the Colorado basin itself, and you know very well, 8.23 million acre feet come from the upper basin into the lower basin. A big aspect of that, especially as it relates to Southern Arizona, of course, is the Central Arizona project and its right in terms of Colorado River. What we are projecting is that within—by around 2020, demand will in fact exceed supply given current trends in terms of drought and given current trends in terms of temperature and its impact on snow. One of the things that we should keep in mind regardless of how change is attributed—human, natural or both—is that we have to adapt. There will be floods, droughts and hurricanes in the future. There is no denying that. I can't say very much about the migration issue. It is not an area that I know anything about. From the standpoint of Southern Arizona, what we are seeing is increased pressure on groundwater resources for development purposes and increasing reduction and reliability of Colorado River flow to support that. There is a slew of other issues that are related to that that we are beginning to see as a result of dryness. Some of them include dust storms, as you saw last year. There was a storm blowing into Phoenix. There were quite dramatic pictures of it. And dust is known to have a negative effect on snow melt as well. So there are combined issues from the standpoint of water resource reliability for Southern Arizona.

Dr. EASTERLING. One general principle that I think we all operate with when asking the question how might climate change affect any of the systems is that in environments that are already very dry like Arizona that most of the natural ecosystems are in very delicate balance with the climate conditions and therefore relatively small changes in climate can result in relatively large changes in such things as species composition, in other words, the mix of vegetation types, trees especially in your case, that exist in the less-managed environments of the State and that would be of great concern.

Dr. BURKETT. The IPCC has undertaken a special technical report on water, a paper on water that Dr. Pulwarty and I will be coauthoring. It will come out in about nine months, and if you like, we can come and present those findings to you. Some of the implications for runoff in the arid Southwest, for example, suggest through the models—and all this will be captured in the report—a decline in surface water availability and runoff that will intensity during the next 50 years.

Dr. PULWARTY. I would want to add something to what Bill is saying—Dr. Easterling—we have very little understanding of the increased impact on non-managed systems and you can see it in terms of the pinion die-off in Southern Arizona and changes in the forest. What I would like to mention in that context is that the present drought that we are experiencing in the basin is 1.5 degrees Fahrenheit warmer than the drought in the 1950s, and that has—that temperature stress has in fact created much larger impacts on the non-managed areas than even during the 1950s. So my point being is however we attribute change, change is happening and therefore we need to look at adaptation responses.

Ms. GIFFORDS. Mr. Chairman, just a quick follow-up. Some of my concern is, Arizona is now the fastest growing State in the Nation so everyone wants to move there. It is a wonderful place this time of year, but I believe because of this increased growth we have additional concerns in terms of—you know, we just—we are going to have a lot more emissions, we are going to have a lot more fuel demands. Meanwhile, we have this really delicate ecosystem there and the situation with the Colorado River water which—and I am afraid that we just don't adequately know how to manage all of this.

Dr. PULWARTY. One of the things that we have to be clear on is this being able to picture the risks that we are facing in one setting. There are these increasing population demographic pressures as you are describing but in addition, at the same time we are seeing more collaborative agreements between Nevada and Arizona on water storage and so on. So we need to look at what some of those adaptation mechanisms are.

Chairman GORDON. The gentlelady's time has expired.

Mr. Inglis.

SUNSPOTS

Mr. INGLIS. Thank you, Mr. Chairman. Before I ask about sea walls, I wonder if somebody can give me an explanation of the sun theory that Mr. Rohrabacher mentioned and the reaction to that?

Chairman GORDON. I think that sunspots are really what is causing this and it is not really global warming. If anybody would like to address that?

Dr. SCHNEIDER. Well, I can address aspects of it. I have worked on the problem earlier though not recently, and I could give you the names of people who work on it directly now, but again, I will present the summary from what I have heard from the debates among colleagues. If the energy output of the sun itself in terms of the total number of watts of energy over every square meter had changed significantly, and that was responsible for the warming, then there would be particular fingerprints of that that you would see in the system. If you increase the energy output of the sun, you would find the stratosphere, you know, the layer above 10 to 50 miles warming, you would find the middle of the atmosphere warming, the lower and the surface. If that warming were due to human effects, greenhouse gases and ozone-depleting substances, then the fingerprint would be a cooling of the stratosphere because of the decrease in ozone plus some other, what we call rays enforcing factors, and warming of the lower atmosphere. When climatologists in the Working Group I—and again, you should talk with them about this more. But when they assign high confidence to the fact that humans have been implicated at least in the warming of the last 30 years, it is because that particular fingerprint, cooling in the stratosphere and warming in the lower atmosphere, is what occurred. So it is much more consistent with the notion that it was human effects more than natural. Now, nobody has denied that natural isn't part of it, and in fact work I have been personally part of using plants and animals as surrogate thermometers, Terry Ruud et all, and she is testifying at another hearing at the moment, what we have found is that when we use models driven only by natural forces, which include volcanoes and solar effects, that you predict a small fraction of the observed changes in species, that is, when birds come back from migration, when plants bloom and so forth. When we use anthropogenic, you get a better fraction, and when you use them combined, you get the best fraction. So what we would argue is that the climate of the most recent half decade is a mixture of human and anthropogenic factors.

There is one more component of the sun which is more controversial, which is assuming it is not the energy output of the sun that has created the problem, because this is way too small for that, but that changes in magnetic fields and particles has affected the chemistry of the stratosphere and it becomes a trigger to create a major amplifier for global warming. It is a very complex, and I would argue somewhat speculative theory. Working Group I scientists have considered it unlikely. There is a very passionate debate in the literature on it, and if you ask me formally, I will be delighted to send you the somewhat unpleasant articles written by the various people who are involved. But the one thing I can say is that those scientists who have claimed that is isn't the energy output of the sun, but of these magnetic and particle effects have never shown how many watts of energy around the planet can be affected by the hypothesis. Without showing the scale at which the sun could do it, it is very difficult to compete that against the human effects because we have very good idea what the scale of human effects are from greenhouse gases, though as I said earlier, we have much less of an idea about the scale of effects on aerosols. So I think that the jury is still out on the relative importance of the sun, but it is very difficult to dismiss the preponderance of evidence which shows the observational record with and without global warming in the model checked against the observational record. It is very difficult to dismiss that as an accident and require the sun, and my own personal view, having been doing climate theory work now for 35 years, is the sun can't be thrown as irrelevant but that in the last 30 years it is probably not a very large component of the major change.

SEA WALLS

Mr. INGLIS. Mr. Chairman, I hope I have time to ask about the sea walls. It strikes me, you know, obviously there is a huge challenge in places like Indonesia but also places like Hilton Head in South Carolina, which is near where I grew up. Some high-value real estate that could be very affected but not many feet or inches, really, worth of change, and just particularly with the discussion earlier of the levies, I wonder how realistic it is to combat that or see an adaptation involving sea walls. Maybe you discussed this earlier and I wasn't here but at another hearing but tell me about sea walls and them as an adaptive strategy.

Dr. BURKETT. Sea walls have the effect of preventing the inland migration of coastal habitats as sea level rises, and we point that out in our chapter. Sea walls and also a fortified coast tend to prevent freshwater runoff from getting to the coast and sediments from getting to the coast, disrupting sediment transport, you know, back and forth across the coastal zone. With that said, where society deems that protection is the right way to go because of infrastructure or people, whatever that is important to protect, our report suggests that the design of those protective structures would be more effective in the long run, more cost-effective if they consider the fact that sea-level rise will accelerate this century very likely, even if emissions were cut off. First, because the change is already made to the atmosphere, and second, increased intensity of storms in your area, for example, would warrant a specific design consideration of these changes that we describe.

Chairman GORDON. The gentleman's time has expired unless you would like to explore that further?

Mr. INGLIS. Thank you, Mr. Chairman.

Chairman GORDON. Would the gentleman from Georgia like to conclude?

THE IPCC PROCESS

Mr. GINGREY. Mr. Chairman, if you will indulge me, I appreciate that very much and I wanted to ask really all the panelists and maybe very briefly respond. I know, Dr. Rosenzweig, you have been involved in all four of the IPCC assessments and I would just like to know in regard to the process, the changes maybe that have occurred over the period of time, this being the Fourth Assessment. Is the product that you are producing now, do you all—is there a consensus agreement that it is going to be very helpful to us in regard to the policies that we have to set and certainly we are going to face that sooner rather than later?

Dr. ROSENZWEIG. I also have worked on all four assessments. This one as a coordinating lead author, I began four years ago with an expert workshop, a meeting with experts around the world to begin to do the assessment of the observed changes now, because this was the first time we had a chapter for Working Group II on the changes that are occurring now. The process is measured and fully reviewed and that is the basis of the science, and it is I think that strong foundation of the science that goes through expert and government review provides for a product that we—that does then stand and provide the document—is the document of record for the following five years.

Mr. GINGREY. Thank you, Dr. Rosenzweig. Dr. Easterling.

Dr. EASTERLING. Yeah, I would have to add to what Dr. Rosenzweig has said and to say that since I have also been involved in more than one IPCC assessment, it is very clear that the governments of the world are taking more and more ownership of this process, and in a positive way. They are providing the scientists with the key questions that they would like to have addressed and I think we as scientists have felt that we have been given good guidance and the latitude to be able to, no pun intended, to be able to respond and put our best scientific judgments out for all to see in a very fair way.

Mr. GINGREY. Dr. Pulwarty.

Dr. PULWARTY. The scale at which the information is produced to the IPCC meets certain needs, that of the international community. What we are seeing, certainly from the climate change science program synthesis and assessment reports, is what means to different parts of the U.S. and how we interpret and interact with people and the types of decisions that they will make. So one caveat that I would make relative to the other comments is the process has worked very well, but there is that extra step that needs to be taken and we are seeing those within the synthesis and assessment reports that are being produced specifically for the U.S.

Mr. GINGREY. And Dr. Schneider.

Dr. SCHNEIDER. Yes. Thank you. I would share the views of my colleagues that the process is essential for a variety of reasons and I recall having been involved in many U.S. National Research Council studies well before IPCC. When IPCC was first proposed in 1988, I was asked my opinion about what I thought and I said oh, my gosh, we spend so much of our time flying around the world, don't do this to us again. We won't reach different conclusions than we have had in the studies in Australia and the U.K. and so forth. In fact its first general Chairman, Bert Baline, said the rest of the world hasn't participated and they don't entirely trust the developed countries to give them the straight story. So IPCC was set up to create credibility across the international community by having the active participation of over 100 governments. They also dictate the outlines so when you asked us, would this be of useful utility to policy-makers, the answer is to the extent that the policy-makers created the outline which dictates what we must work on, we hope so. But I agree also with Roger Pulwarty that it won't be quite as regionally specific as some countries need and that is where their own research councils can add a supplement. And finally, that government ownership is absolutely critical for the eventual cooperative strategies that we will have to have though as the two staff sitting next to you know, sometimes you have 40-hour sessions to get there and we wish the process occasionally were a little less contentious but it is amazingly comprehensive and the peer review, as Cynthia Rosenzweig pointed out, is why the reports have such high credibility.

Mr. GINGREY. Thank you very much, Mr. Chairman. Thank you for your indulgence.

Chairman GORDON. Thank you.

Since the gentleman brought that question up, let me ask, does anyone on the panel feel like in some cases the summary did not reflect the full views of the information before because of some, for lack of a better term, political pressure? No one thinks that occurred? Yes?

Dr. SCHNEIDER. I have never been one to let the perfect crowd out the good or to say that an 85 percent excellent report should be given a bad grade because it wasn't 98 and it is absolutely amazing how much of the basic underlying science was in the summary for policy-makers, but there were a few casualties that I think were significant. We had a regional table that would actually come closer to Mr. Gingrey's wish being more specific on regional effects. Whether it disappeared because in the U.N. process where consensus, meaning any one or two countries effectively, forces the lowest common denominator was responsible, whether we ran out of time, it is hard to say. I think the single biggest loss from the report was a table that was produced which showed the sectors, the relative increasing damages of function of temperature. It is reflected in Table 19.1 in my testimony but this was a summary table. Above it in the submission from lead authors was a set of timelines which showed when in 2020s, 2050s, 2080s one might achieve two degrees, four or six degrees, because when you look at the damages and you see them increasingly rapidly as you add degrees of warming but you have no idea whether we are going to be at one or at three or at five but it shows you the substantial likelihood that we are going to see at least the middle of that range and could very well at first decimal point odds reach the right-hand edge, and we were very disappointed that that was removed on the basis of a few countries' opposition though we were proud of the United States for supporting that though were not thrilled when the United States removed all reference to dangerous anthropogenic interference. I do not know why. But again, anybody who throws 85 percent of their passes ends up in the Hall of Fame so overall we are quite satisfied with the report.

Chairman GORDON. This is a recommendation for B students. Yes, ma'am?

Dr. ROSENZWEIG. I think what is very important for the scientists is that the underlying documents were not changed, so that anyone who wants to see the entire work of the scientists, can find it there in terms of the tables, scenarios, and trajectories that Dr. Schneider just mentioned. The confidence levels of every statement are in the underlying document, and that they are not changed is extremely important for the science.

Chairman GORDON. Thank you. Well, all good things have to come to an end. We thank you not only for your testimony today but more importantly, for the years of hard work you put in. We look forward to four years from now hearing from you again hopefully with better prognostication. Under the rules of the Committee, the record will be held open for two weeks for Members to submit additional statements that have any additional questions they might have for the witnesses. If there are no objections, the witnesses are dismissed and the hearing is adjourned.

[Whereupon, at 12:23 p.m., the Committee was adjourned.]

Appendix 1:

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Cynthia Rosenzweig, Senior Research Scientist, NASA Goddard Institute for Space Studies, The Earth Institute at Columbia University

Questions submitted by Representative Ralph M. Hall

Q1. The Summary for Policy-makers states that many projected climate change impacts can be reduced by mitigation. In your area of expertise, specifically which projected impacts can be reduced by mitigation? Over what time frame would mitigation reduce those impacts? What are the options for adaptation to those impacts? How much would it cost to adapt versus mitigate for those impacts?

A1. For agriculture, projected impacts that can be reduced by mitigation include reduction in yields due to high temperature stress, droughts, and floods; reductions in yields due to changing agricultural pests; and reductions in yields due to saltwater intrusion in coastal areas. Global climate model and crop model simulations show that mitigation would reduce those impacts in the second half of this century, roughly from the 2050s on. Adaption options for impacts on agriculture include shifting planting dates, switching crop varieties and species, breeding for heat, drought, and flood tolerance, and shifting of agricultural zones to higher latitudes and away from coasts. In regard to costs, it is difficult to directly costs of mitigation and adaptation on a sector-by-sector basis. Mitigation is addressed through a set of larger-scale processes (e.g., reducing emissions of greenhouse gases from energy generation), while adaptation is a process that occurs on more local levels (e.g., at the scale of a farming region). That being said, projections for agriculture show that at longer timeframes climate change is likely to cause negative effects on regional and global agricultural production, beyond which adaptive measures may not be effective. Thus, as stated by the IPCC Working Group II, mitigation and adaptation are both needed to reduce both short-term and long-term risks of climate change.

Q2. The report states that 20 to 30 percent of plant and animal species are likely to be at increased risk of extinction if global temperatures exceed 1.5 to 2.5 degrees Celsius above 1990 levels. Over what timeframe would these extinctions occur? What would be the normal expected extinction rate over that time frame (i.e., the extinction rate without temperature increase)?

A2. In many but not all scenarios, the temperature levels projected and thus species extinctions are expected to occur within this century. The uncertainties remain large, however, since for about two degrees C temperature increase (above pre-industrial levels) the percentage of species extinctions may be as low as 10 percent or for about three degrees C as high as 40 percent. Depending on the biota, the full range is between one percent and 80 percent. The IPCC Working Group II assigned the statement about species extinctions 'medium confidence,' which is defined as 'about five out of 10 assessed chance of being correct.' The estimates for extinction that the IPCC provides are based on climate change forcing alone. As for what the extinction rate would be without climate change, those estimates also vary because of differences in land-use change predictions. Species extinction estimates for changes related to habitat destruction from land-use change alone range from one percent to about 30 percent, depending on the biome (Thomas, 2004). Beyond climate change and land-use change, there will be other driving forces that may compound the stress that ecosystems experience—in same cases affecting the same species but in others threatening new ones.

C.D. Thomas et al. 2004. Extinction risk from climate change. *Nature* 427:145–148.

Questions submitted by Representative Dana Rohrabacher

Q1. Did you experience or feel any restrictions or censorship from your agency regarding the work you did on the documents you have produced as a result of your work related to the IPCC or, in general, climate change?

A1. In regard to my work related to the IPCC, I did not experience restrictions or censorship from my agency. In regard to my work related to climate change, I have experienced restrictions from my agency. To give one example, a press release describing my work on climate change effects on agriculture was initially suppressed and subsequently revised.

Q2. In your testimony, you list three significant limitations/gaps in knowledge in order to attribute warming to human origin. It seems that these limitations *would also apply to limitations in the understanding of warming in general, human-caused or not. Please explain how these gaps in knowledge apply only to human-caused climate change. And how can you and/or the IPCC say that certain findings are 'highly likely' given these gaps?*

A2. The process of considering the causes of warming takes into account possible causes and uses global climate models to compare warming from the various causes of observed warming. The IPCC assigns uncertainties to the radiative forcing factors and climate scientists include these uncertainties in the global climate model experiments. The simulations show that when human causes are included in the model simulations there is better agreement with observations, even given the uncertainties, limitations, and gaps in knowledge. Only by adding the human forcing can the observed warming outside the range of natural variability be satisfactorily explained.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Virginia Burkett, Chief Scientist for Global Change Research, U.S. Geological Survey, U.S. Department of the Interior

Questions submitted by Representative Ralph M. Hall

Q1. The Summary for Policy-makers states that many projected climate change impacts can be reduced by mitigation. In your area of expertise, specifically which projected impacts can be reduced by mitigation? Over what time frame would mitigation reduce those impacts? What are the options for adaptation to those impacts? How much would it cost to adapt versus mitigate for those impacts?

A1. The IPCC WGII defines adaptation as an adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. The IPCC WGII defines mitigation as an anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases. All of the key impacts of climate change (see Table 6.1 below) described in the IPCC coastal chapter could be reduced by mitigation. The time required for mitigation to translate into reduced impacts varies among climate drivers and the biological and physical systems affected. There will be a lag effect of days to decades for some drivers and systems, and the reduction of effects due to temperature or precipitation changes from reduced emissions of some well-mixed greenhouse gases could lag by decades or longer. In other words, even if GHG concentration could be stabilized at year 2000 levels, global temperature would continue to rise for several decades. This "committed warming" due to existing GHG levels in the atmosphere is expected to raise global average temperature another half to one and one half degrees Fahrenheit. On the other hand, the timing of the reduction of direct ecosystem impacts caused by changes in carbon dioxide levels (e.g., photosynthesis and respiration) will generally begin to occur immediately following a reduction in greenhouse gas levels in the atmosphere.

Table 6.1*: Main climate drivers for coastal systems (Figure 6.1), their trends due to climate change, and their main physical and ecosystem effects. (Trend: $\uparrow$ increase; ? uncertain; R regional variability).*

Climate Driver (trend)		**Main Physical and Ecosystem Effects on Coastal Systems (discussed in Section 6.4.1)**
CO_2 concentration ($\uparrow$)		Increased CO_2 fertilisation; Decreased seawater pH (or 'ocean acidification') negatively impacting coral reefs and other pH sensitive organisms.
Sea surface temperature (SST) ($\uparrow$, R)		Increased stratification/changed circulation; Reduced incidence of sea ice at higher latitudes; Increased coral bleaching and mortality (see Box 6.1); Poleward species migration; Increased algal blooms.
Sea level ($\uparrow$, R)		Inundation, flood and storm damage (see Box 6.2); Erosion; Saltwater Intrusion; Rising water tables/ impeded drainage; Wetland loss (and change).
Storm	Intensity ($\uparrow$, R)	Increased extreme water levels and wave heights; Increased episodic erosion, storm damage, risk of flooding and defence failure (see Box 6.2);
	Frequency (?, R)	Altered surges and storm waves and hence risk of storm damage and flooding (see Box 6.2).
	Track (?,R)	
Wave climate (?, R)		Altered wave conditions, including swell; Altered patterns of erosion and accretion; Re-orientation of beach planform.
Run-off (R)		Altered flood risk in coastal lowlands; Altered water quality/salinity; Altered fluvial sediment supply; Altered circulation and nutrient supply.

Many of the indirect effects of climate change on coasts, however, are "higher-order" impacts that will lag in response to mitigation. Sea level rise is the best example of this latent systems response. Our IPCC coastal chapter authors conclude that:

> Sea-level rise has substantial inertia and will continue beyond 2100 for many centuries. Irreversible breakdown of the West Antarctica and/or Greenland ice sheets, if triggered by rising temperature, would make this long-term rise significantly larger, ultimately questioning the viability of many coastal settlements across the globe. The issue is reinforced by the increasing human use of the coastal zone. Settlement patterns also have substantial inertia, and this

issue presents a challenge for long-term coastal spatial planning. Stabilization of climate could reduce the risks of ice sheet breakdown, and reduce but not stop sea-level rise due to thermal expansion [Box 6.6]. Hence, it is now more apparent than the TAR [third assessment report] that the most appropriate response to sea-level rise for coastal areas is a combination of *adaptation* to deal with the inevitable rise, and *mitigation* to limit the long-term rise to a manageable level.

Adaptation options vary among coastal types and geographic regions. Adaptation options for coping with coastal erosion in the Arctic are quite different from the adaptation options in the Mississippi Delta because of differences in physical, biological and human influences in these two areas and how climate change is affecting them. In the Mississippi Delta, the delivery of river-borne sediments to the coast is likely to increase the resilience of coastal habitats to sea level rise while the collapse of thawing permafrost and loss of coastal wetlands in the Arctic could not be offset to the same degree by adaptations in river management.

One constraint on the successful reduction of climate-related impacts to coastal systems is the limited ability to characterize in appropriate detail how various coastal systems, and their constituent parts, will respond to climate change drivers and to adaptation initiatives. Also, we point out in our chapter that the response of coastal systems to climate change is not necessarily linear or proportional, and that there are interactions among coastal systems and other factors (such as human development on the coast) that make it difficult to predict precisely how changes in climate (or mitigation) will affect a specific coastal community, marsh, or barrier island. Another key finding regarding adaptation options is that "reactive and stand-alone efforts to reduce climate-related risks to coastal systems are less effective than responses which are part of Integrated Coastal Zone Management (ICZM), including long-term national and community planning." The chapter concludes that greater access to wealth and technology generally increases adaptive capacity while poverty limits adaptation options. A lack of risk awareness or institutional barriers can also have an important influence on adaptive capacity.

Our chapter closes with an assessment of limits and tradeoffs to adaptation and implications for sustainable development. The following excerpt summarizes some of our findings relative to the importance of the combination of adaptation and mitigation for vulnerable coastal regions:

Climate change and sea-level rise increase the challenge of achieving sustainable development in coastal areas, with the most serious impediments in developing countries, in part due to their lower adaptive capacity. It will make achieving the Millennium Development Goals (UN Secretary General 2006b) more difficult, especially in terms of Ensuring Environmental Sustainability (reversing loss of environmental resources, and improving lives of slum dwellers, many of whom are coastal). Adapting effectively to climate change and sea-level rise will involve substantial investment, with resources diverted from other productive uses. Even with the large investment possible in developed countries, residual risk remains, as shown by Hurricane Katrina in New Orleans (Box 6.4), requiring a portfolio of responses that addresses human safety across all events (protection, warnings, evacuation, etc.) and also can address multiple goals (e.g., the environment) (Evans et al., 2004a; Jonkman et al., 2005). Long-term sea-level rise projections mean that risks will grow for many generations unless there is a substantial and ongoing investment in adaptation (Box 6.6). Hence, sustainability for coastal areas appears to depend upon a combination of adaptation and mitigation (Sections 6.3.2 and 6.6.5).

Regarding the cost to adapt versus mitigate, we draw the following conclusion:

Adaptation costs for vulnerable coasts are much less than the costs of inaction (high confidence). Adaptation costs for climate change are much lower than damage costs without adaptation for most developed coasts, even considering only property losses and human deaths. As post event impacts on coastal businesses, people, housing, public and private social institutions, natural resources, and the environment generally go unrecognized in disaster cost accounting, the full benefits of adaptation are even larger. Without adaptation, the high-end sea level scenarios combined with other climate change (e.g., increased storm intensity) are as likely as not to render some islands and low-lying areas uninhabitable by 2100, so effective adaptation is urgently required.

To illustrate that financial costs are also nonlinear with respect to climate change, we present the graphic below of estimated flood damages in coastal Argentina. Note the significant threshold in real estate damage costs when flood levels reach two m (six feet).

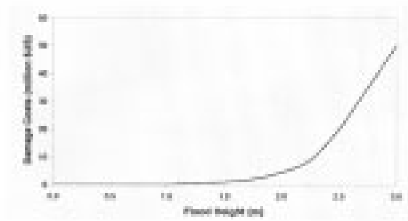

Figure 6.9 [From the IPCC WGII Fourth Assessment Report]: Real estate damage costs related to flood levels for the Río de la Plata, Argentina (Barros et al. 2006).

Q2. The Summary for Policy-makers states that coasts are projected to be exposed to increasing risks, including coastal erosion, due to climate change and sea-level rise and the effect will be exacerbated by increasing human-induced pressures on coastal areas. What are the other human-induced pressures on coastal areas? Even if we decreased greenhouse gas emissions those pressures would still be there, so how would decreasing emissions help coastal communities with these problems?

A2. The human-induced pressures on coastal systems are summarized in the following three paragraphs from our chapter:

> Few of the world's coastlines are now beyond the influence of human pressures, although not all coasts are inhabited (Buddemeier et al., 2002). Utilization of the coast increased dramatically during the 20th Century, a trend that seems certain to continue through the 21st Century (Section 6.3.1). Coastal population growth in many of the world's deltas, barrier islands, and estuaries has led to widespread conversion of natural coastal landscapes to agriculture, aquaculture, silviculture, as well as industrial and residential uses (Valiela, 2006). It has been estimated that 23 percent of the world's population lives both within 100 km distance of the coast and <100 m above sea level, and population densities in coastal regions are about three times higher than the global average (Small and Nicholls, 2003) (see also Box 6.6). The attractiveness of the coast has resulted in disproportionately rapid expansion of economic activity, settlements, urban centers, and tourist resorts. Migration of people to coastal regions is common in both developed and developing nations.
>
> Sixty percent of the world's 39 metropolises with a population of over five million are located within 100 km of the coast, including 12 of the world's 16 cities with populations greater than 10 million. Rapid urbanization has many consequences; for example, enlargement of natural coastal inlets and dredging of waterways for navigation, port facilities, and pipelines exacerbate saltwater intrusion into surface and ground waters. Increasing shoreline retreat and risk of flooding of coastal cities in Thailand (Durongdej, 2001; Saito, 2001), India (Mohanti, 2000), Vietnam (Thanh et al., 2004), and the United States (Scavia et al., 2002) have been attributed to degradation of coastal ecosystems by human activities, illustrating a widespread trend.
>
> The direct impacts of human activities on the coastal zone have been more significant over the past century than impacts that can be directly attributed to observed climate change (Lotze et al., 2006; Scavia et al., 2002). The major direct impacts include drainage of coastal wetlands, deforestation and reclamation; and discharge of sewage, fertilizers, and contaminants into coastal waters. Extractive activities include sand mining and hydrocarbon production; harvests of fisheries, and other living resources; introductions of invasive species; construction of sea walls and other structures. Engineering structures, such as damming, channelization, and diversions of coastal waterways, harden the coast, change circulation patterns and alter freshwater, sediment, and nutrient delivery. Natural systems are often directly or indirectly altered, even by soft engineering solutions, such as beach nourishment, and foredune construction (Hamm and Stive, 2002; Nordstrom, 2000).

Yes, these human-induced pressures that are independent of climate change will likely be present during the coming decades even if emissions are reduced. These are also likely to intensify as coastal populations grow in the future, placing additional stress on coastal resources. We conclude that "[c]urrent pressures are likely to adversely affect the integrity of coastal ecosystems and thereby their ability to cope with additional pressures, including climate change and sea-level rise. This is a particularly significant factor in areas where there is a high level of development, large coastal populations and high levels of interference with coastal systems." The reduction of greenhouse gas emissions alone will not eliminate potential impacts, as noted in the following excerpt from our chapter:

> Adaptation (e.g., coastal planning and management) and mitigation (reducing greenhouse gas emissions) are responses to climate change, which can be considered together (King, 2004) (see this volume Chapter 18). The response of sea-level rise to mitigation of greenhouse gas emissions is slower than for other climate factors (Meehl et al., 2007) and mitigation alone will not stop growth in potential impacts (Nicholls and Lowe, 2006). However, mitigation decreases the rate of future rise and the ultimate rise, limiting and slowing the need for adaptation as shown by Hall et al. (2005). Hence Nicholls and Lowe (2006) and Tol (2006) argued that adaptation and mitigation need to be considered together when addressing the consequences of climate change for coastal areas. Collectively these interventions can provide a more robust response to human-induced climate change than consideration of each policy alone.
>
> Adaptation will provide immediate and longer-term reductions in risk in the specific area that is adapting. On the other hand, mitigation reduces future risks in the longer-term and at the global scale. Identifying the optimal mix is problematic as it requires consensus on many issues, including definitions, indicators and the significance of thresholds. Importantly, mitigation removes resources from adaptation, and benefits are not immediate, so investment in adaptation may appear preferable, especially in developing countries (Goklany, 2005).

ANSWERS TO POST-HEARING QUESTIONS

Responses by Roger S. Pulwarty, Physical Scientist, Climate Program Office, Office of Oceanic and Atmospheric Research, National Oceanic and Atmospheric Administration, U.S. Department of Commerce

Questions submitted by Representative Ralph M. Hall

Q1. The Summary for Policy-makers states that many projected climate change impacts can be reduced by mitigation. In your area of expertise, specifically which projected impacts can be reduced by mitigation? Over what time frame would mitigation reduce those impacts? What are the options for adaptation to those impacts? How much would it cost to adapt versus mitigate for those impacts?

A1. The mitigation measure of reducing anthropogenic greenhouse gas emission can reduce a number of projected climate change impacts. Reducing worldwide greenhouse gas emissions now would eventually act to:

(1) Reduce the future severity of drought in the U.S.,
(2) Reduce the level of ocean acidification affecting coral reefs,
(3) Reduce the severity of coral bleaching events (e.g., a 1–3°C increase in global temperature would result in more bleaching events with small recovery times, whereas an increase of 2.5–3.0°C could result in widespread mortality), and
(4) Reduce the decline of Arctic sea ice and the rise of sea level.

Because of inertia in the climate system, it would take several decades for any benefits from mitigation efforts to materialize, hence the need for adaptation in the short-term. According to the Intergovernmental Panel on Climate Change (IPCC) modeling and studies, even if complete mitigation were put into place immediately (meaning even if worldwide anthropogenic carbon dioxide emissions were immediately reduced to zero), because of existing carbon dioxide in the system, models indicate we are committed to a 0.6°C (1°F) temperature change over the next 50 years.

Many of the unavoidable near-term consequences of global warming can be addressed through adaptation strategies such as building levees and restoring wetlands to protect coasts, altering farm practices to grow crops that can survive higher temperatures, building infrastructure that can withstand extreme weather, and implementing public health programs to help people in cities survive major heat waves. Some of these adaptations can provide double dividends in that they may: (a) enhance resilience and reduce current vulnerabilities to current climate-sensitive problems including climate variability, as well as (b) help cope with future impacts of climate changes. As temperatures continue to rise the options for successful adaptation diminish and the associated costs increase. Some near-term adaptation strategies may increase local vulnerability in the longer run. For example in a case where levees designed to protect the coast also encourage development along the coast, i.e., in vulnerable regions or when the perceived threat has faded from memory. Another example would be a case where population grows in response to temporarily increased water (due to temperature increases) from glacier-fed rivers that might ultimately disappear.

The World Bank (2006) estimates that $10 billion–$40 billion per year may be required for that agency to "climate proof' its development projects. No similar calculations have been done at the national scale for the United States. It is important that the costs of mitigation be weighed against the rising costs of adaptation in the future. Many mitigation efforts can provide additional benefits outside of their target. For example, depending on the approach, implementing the mitigation strategy of reducing greenhouse gas emissions can lead to reduced air pollution, which benefits both public health and agriculture. Thus many mitigation efforts themselves may offset some fraction of mitigation costs. The direct costs of mitigation should also include the potential for longer-term economic benefits of new technology markets being developed in response to climate change.

Adaptation strategies are discussed in the context of droughts and flood below, in response to Questions 2 and 3.

Q2. The report predicts that drought-affected areas will increase. What parts of the U.S. are vulnerable to this problem? What amount or percentage increase is predicted? Over what time frame? What could communities do to adapt to increased drought? If we mitigated greenhouse gas emissions, when would we observe a reversal of the drought increases?

A2. The main areas likely to be affected within the U.S. are the watersheds of the Colorado River Basin, the Sierra Nevadas, and the Great Lakes. There is a broad consensus among climate models that the Western U.S. (including the western Great Plains) will become drier in the 21st century and that the transition to a more arid climate may already be under way. The inflow into Lake Powell on the Colorado has been significantly below average for all but one year since 1999. Most climate models and scenarios suggest that in the prairies there will be a decrease in soil moisture (which may decrease average crop yields by 10–30 percent). If these models are correct, the levels of aridity of the recent multi-year drought or the Dust Bowl and the 1950s droughts may become the new climatology of the American Southwest within a time frame of years to decades. It is important to note that the IPCC to date does not explicitly predict the magnitude and timing of drought consequences because these depend on the amount and rate of warming, and, in some cases, on society's ability to adapt. Table 1 shows the most recent trends and projections over North America:

Water resource change	***Examples from AR4***
1 to 4 week earlier peak streamflow due to earlier warming-driven snowmelt	US West and US New England regions
↓ proportion of precipitation falling as snow	US West
↓ duration and extent of snow cover	most of North America
↑ annual precipitation	most of North America
↓ mountain snow water equivalent	Western North America
↓ annual precipitation	Central Rockies, Southwestern US, and Eastern Arctic
↑ frequency of heavy precipitation events	most of US
↓ runoff and streamflow	Colorado and Columbia River Basins
widespread thawing of permafrost	most of Alaska and Canada
↑ water temperature of lakes (0.1 to 1.5°C)	most of North America
↑ streamflow	most of US East
glacial retreat or decline in glacial mass	U.S. western mountains, Alaska and Canada
↓ ice cover	Great Lakes, Gulf of St Lawrence
↑ dry days (timing between rainfall events)	most of North America
salinisation of coastal surface waters	Florida, Louisiana
salinisation of ground water	Manitoba
↑ periods of drought	Western US, Southern Canada

In the case of the Sacramento-Joaquin River and the Colorado River basins in the Western United States, for example, streamflow changes projected beyond 2020 indicate that it may not be possible to fulfill all of the present-day water demands (including environmental targets), even with adapted reservoir management (with flows declining anywhere from 17–25 percent). By 2050 the Sacramento and Colorado River deltas could experience dramatic increases in salinity and subsequent ecosystem disruption.

The challenges of managing water in the Columbia River basin will likely expand with climate change due to changes in snowpack and seasonal flows. The ability of managers to meet operating goals (reliability of supply for particular economic and environmental needs) will likely drop substantially under climate change. Reliability losses are projected to reach 25 percent by the end of the 21st century and interact with operational rule requirements. For example, maintaining current operating rules would reduce firm power reliability by 10 percent under present climate and 17 percent in years during the warm phase of the Pacific Decadal Oscillation. Adaptive measures have the potential to moderate the decrease in April snowpack, but lead to 10–20 percent losses of firm hydropower and lower than current summer flows (important for fish). The IPCC projects an extended fire season for North America as well as increased threats from pests and disease (which could significantly enlarge the area burned in a fire). Moreover, because fires release the carbon stored in trees, an increase in wildfires would accelerate rates of climate change.

The seasonality of key impacts is thus important but is little understood. Integration of climate change adaptation into regional planning processes is in the early stages of development.

As stated in the answer to Question 1 (above), due to the inertia in the climate system it will be several decades before any benefits from mitigation efforts materialize, hence the need for adaptation. A mixed portfolio of adaptation and response strategies are needed, with strong emphases on "learning by doing" as society moves from event to event, and response to response. Some lessons are available from integrated and collaborative programs between federal, states, local and private partners such as the Colorado River and Columbia Basins Adaptive Management Program, and early warning and impacts assessments systems being developed such as the National Integrated Drought Information System and the Regional Integrated Sciences and Assessments Programs.

The *California Water Plan* (2005) identifies two dozen water and land management strategies that can be considered by regional and local entities. These strategies serve to reduce water demand, increase water supply, improve water quality, practice resource stewardship, improve operational efficiency, and facilitate transfers. In California, urban water-use efficiency and recycled municipal water together could provide over four million acre-feet annually, while additional groundwater and surface water storage have the potential for as much as three million acre-feet of annual supply. Adaptation strategies in drought impacted areas could also reduce impacts on plants being used for biofuel development and water for hydropower.

With mitigation we would not see a reversal of drought increase for several decades, but we may see less frequent and less dramatic events. Smaller natural drought events would not be exacerbated by anthropogenic climate change.

Q3. The report predicts that heavy precipitation events will increase and cause increased flood risk. What parts of the U.S. are vulnerable to this climate change impact? What amount or percentage increase is predicted? Over what time frame? What could communities do to adapt to increases flood risk? If we mitigated greenhouse gas emissions, when would we observe a reversal of the increased flood risk?

A3. Many coastal and riparian communities and habitats in the U.S. are vulnerable to increased flood risk due to impacts from climate change. As identified in Table 1 (see Question 1, above) the most recent trends and projections over North America include projections of increased frequency of heavy precipitation events across most of the United States, increased annual precipitation across most of North America, and increased streamflow in most of the eastern United States. Further, sea level is rising along much of the coast, and the rate of sea level change is projected to increase in the future. Any increase in sea level could exacerbate the impacts of progressive inundation, storm-surge flooding, and shoreline erosion. In addition to increased flood risk from climate change impacts, coastal communities and habitats will also be stressed by impacts associated with development and reduced water quality. Storm impacts are likely to be more severe, especially along the Gulf and Atlantic coasts. Flood hazards are not limited to the coastal zone. River basins with a history of major floods (e.g., the Sacramento, the Red River, the upper Mississippi), illustrate the sensitivity of rivers to extreme events and highlight the critical importance of infrastructure design standards, land use planning, and weather/flood forecasts.

The IPCC projects but does not explicitly predict the magnitude and timing of increased flood risk on coastal and riparian communities because the risk depends on the amount and rate of warming and, in some cases, on society's ability to adapt.

In order for communities to adapt to increased flood risk, it is important that they be aware of early indicators of change in the physical system and also of thresholds that affect management priorities. Water managers in some countries are already considering explicitly how to incorporate the potential effects of climate change into specific designs and multi-stakeholder settings. Integrated water resource and coastal zone management are based around the concepts of flexibility and adaptability, using measures which can be easily altered or are robust to changing conditions. For example, in several states adaptive management measures (including water conservation, reclamation, conjunctive use of surface and groundwater and desalination of brackish water) have been advocated, but not yet fully implemented, as a means of proactively responding to climate change threats on water supply. Similarly, resilient strategies for flood management and environmental restoration, such as allowing rivers to temporarily flood and reducing exposure to flood damage, might be preferable to (or combined with) traditional "resistance" (protection) strategies.

As stated in answer to Question 1 (above), because of inertia in the climate system, it would take several decades for any benefits from mitigation efforts to materialize, hence the need for adaptation in the short-term. According to IPCC modeling and studies, even if complete mitigation were put into place immediately (meaning if anthropogenic carbon dioxide emissions were immediately reduced to zero), because of existing carbon dioxide in the system, models suggest we are committed to a 0.6°C (1°F) temperature change over the next 50 years, and any associated impacts created by this temperature change.

Questions submitted by Representative Dana Rohrabacher

Q1. Did you experience or feel any restrictions or censorship from your agency regarding the work you did on the documents you have produced as a result of your work related to the IPCC or, in general, climate change?

A1. No. I did not experience or feel any restrictions or censorship from my agency in the context of IPCC-related work.

Q2. In your testimony, you note that unmitigated Climate change could in the long-term exceed the capacity of the different natural, managed and human systems to adapt. Please give us your opinion *about that minimum point, say measured in temperature increase or greenhouse gas concentration that this might happen?*

A2. The IPCC concluded there is high confidence that the ability of ecosystems to adapt naturally to climate change is likely to be exceeded over the next century. Irreversible or abrupt impacts from the interactions between climate and other changes and drivers can lead to decline of about 20–30 percent of species assessed so far for average warming exceeding 1.5–2.5°C and significant (with high confidence) of greater than 40 percent assessed at 4°C. A description of projected impacts that we might expect to see with increasing thresholds of temperature change includes:

a. 1–2°C—Increased risk of extinction 20–30 percent of species assessed so far, most corals bleached (with attendant economic impacts)
b. 2–3°C—Major changes in natural systems, including widespread coral mortality
c. 3–4°C—About 30 percent of coastal wetlands lost (reducing storm buffers and productivity)
d. 5°C—Extinction of more than 40 percent species assessed

Other as yet little understood impacts relate to outbreaks of pests such as the bark beetle affecting forest conditions and wildfire risks. The thresholds in such cases are related to night-time temperature increases, such as is the temperature increases occurring the West, which increases the viability of the organisms concerned.

Q3. In your testimony you list five efforts in developing research and management partnerships. In your opinion, *what timeline would be needed to develop these efforts in order for them to have a significant effect on adaptation planning?*

A3. In order to have a significant effect on adaptive planning, developing research and management partnerships require:

- Enhancement of networks of systematic observations of key elements of physical, biological, managed and human systems affected by climate change, particularly in regions where such networks have been identified as insufficient;
- Research into understanding and managing physical, biological and human systems where there is a risk of irreversible change due to climate and other stresses;
- Increased understanding of the potential costs and benefits of impacts due to various amounts of climate change, of damages avoided by different levels of emissions reduction, and of options for adapting to these impacts and managing the risks;
- Studies to explore how adapting to climate change and the pursuit of sustainable development can be complementary; and
- "Learning by doing" approaches, where the base of knowledge is enhanced through accumulation of practical experience.

Each of these elements is already being undertaken to some extent, but each is disparate, limiting the comparison of lessons learned and the diffusion of innovations. In the case of a limited systematic network of observations, it becomes difficult to ascertain the baseline against which projected changes are to be judged and thus the economic benefits of having such information. In this situation is increasingly important to adapt through changes proactively and as events occur. A mixed portfolio of strategies is needed, with strong emphases on "learning by doing" across sectors as society moves from event to event and response to response.

Some lessons are available from integrated programs between federal, states, local and private partners such as the Colorado and Columbia River Basins Adaptive Management Programs, and early warning and impacts assessments systems being developed such as the National Integrated Drought Information System and the Regional integrated Sciences and Assessments Programs. The time scales for implementation of such collaborative programs are two years for developing or building on existing but not yet coordinated networks at the local, State and regional or watershed levels, and 5–10 years to reach effective implementation. We are likely to experience the benefits of adaptation more immediately than the benefits of mitigation, and adaptation would also reduce societal vulnerability in some areas to climate variability as well as changes. Given the rates and magnitudes of climate changes (and, in many cases, the as yet uncertain relationships between anthropogenic temperature changes and climate variability including El Niño, decadal-scale changes in hurricane numbers, multi-year drought duration and magnitude) mitigation by itself will not prevent climatic risks.

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ANSWERS TO POST-HEARING QUESTIONS

Responses by Stephen H. Schneider, Melvin and Joan Lane Professor for Interdisciplinary Environmental Studies; Professor, Department of Biological Sciences; Senior Fellow, Center for Environmental Science and Policy at the Woods Institute for the Environment, Stanford University

Questions submitted by Representative Ralph M. Hall

Q1. The Summary for Policy-makers states that many projected climate change impacts can be reduced by mitigation. In your area of expertise, specifically which projected impacts can be reduced by mitigation? Over what time frame would mitigation reduce those impacts? What are the options for adaptation to those impacts? How much would it cost to adapt versus mitigate for those impacts?

A1. Mitigation. How mitigation would lower the impacts of projected climate changes depends on the amount of mitigation relative to a projection of unmitigated greenhouse gas increases-the so called "baseline"—as well as which impact is being considered. Recall in my written testimony I pointed out that IPCC showed that the number of "key vulnerabilities" and their intensities increase substantially with warming levels. In that prepared testimony I included the summary Table 19.1 from the IPCC Working Group II Fourth Assessment Report, which maps levels of warming with projected impacts. To give a few examples, the loss of species is estimated to be greater than 40 percent of known plants and animals for warming above four degrees Celsius, but would be less than 20 percent for warming less than 1.5°C above 1990 levels. Similarly, commitment to near total deglaciation of Greenland Ice Sheet—with more than five meters of sea level rise over centuries to millennia—is projected as likely for warming of 4°C or more, but for warming under 1.5°C some melting is inevitable, but much less and thus much less sea level rise. Similar statements could be made about hurricane intensity, wildfire incidence, etc.

The projected "likely" range of future warming to the end of this century from Working Group I was in the range of 1.1 to 6.4°C above 1990 levels. About half this uncertainty is due to insufficient understanding of the climate sensitivity—a property of the climate system. The other half of the uncertainty range is at our control: via emissions decisions. If we chose as a matter of policy to invest in less polluting technologies (e.g., the A1T scenario from IPCC), then we could have a much greater chance of staying below 2°C additional warming, whereas if we persist on a more business as usual pathway with fossil fuel intensive emission (e.g., the A1FI scenario from IPCC), then it is much more likely to exceed that level of warming and trigger a much large number—and degree of intensity—of key vulnerabilities.

Working Group III summarizes costs of mitigation, concluding, again in very broad terms, that typically proposed mitigation activities cost somewhere from a few tenths of a percent *gain* in the GDP up to several percent loss over the time frame of a half century. The WGIII authors also note that this is a small fraction of the usually projected growth rate of the world economy—typically estimated to be at least two percent per year. Thus, if the economy in 2050 were to be two percent lower than baseline levels due to mitigation policies that reduced CO_2 levels by, say, 100 parts per million, even that level of costs would be made up in one year of normal economic growth.

Adaptation. As to costs of adaptation, that is the subject of Chapter 20 of Working Group II, and again it is very difficult to generalize other than to say that for less warming, adaptive measures are much less costly than for more warming—when in fact adaptation may not even be feasible. Indeed, in Table 19.1 you will note that for many entries we categorize them as "key" impacts or vulnerabilities precisely because above certain temperature levels adaptive capacity is markedly reduced. It is difficult to generalize across the many sectors of impacts and the economic status of groups—which itself markedly affects adaptive capacity. However, some broad generalizations include that human systems—such as agriculture—especially in cooler places with well developed economies—have much higher adaptive capacity than similar systems in hotter and poorer countries and that natural ecosystems typically have the least adaptive capacity.

Finally, I do not see adaptation and mitigation as trade-offs, but rather as complements, since some degree of climate change is likely—at least two degrees C warming above pre-industrial levels is a better than even bet in my view—and thus some adaptation is essential to reduce impacts. But since the literature suggests that adaptive capacity goes down quickly with warming above a few degrees, this implies the need for mitigation over time to prevent reaching such levels of climate change, though whether to label any level as "dangerous" involves both scientific assessments and value judgments.

Questions submitted by Representative Dana Rohrabacher

Q1. In your testimony you quote Article Two of the UN Framework Convention on Climate Change which. discusses the stabilization level of greenhouse gas concentrations that would prevent dangerous anthropogenic interference with the climate system. What is your opinion *on what that level might be?*

A1. What is judged as "dangerous" climate change is a combination of scientific input on risks (what can happen, what are the odds and to whom would the risks fall) as a function of levels of warming and value judgments on how much risk is "too much"—and thus could be interpreted as "dangerous." Since I have been asked for my personal opinion on this, it will be a mixed judgment: my reading of the scientific literature on the risks and my personal philosophy, which in brief is not to take significant chances with the planetary life support systems.

To be more specific, I believe it is already too late to prevent some dangerous outcomes—in fact increased wildfires in the U.S. West, heat waves in Europe and drying in Mediterranean climates—which includes California—has already co-occurred with the rapid warming trend of the past 40 years. We are committed to at least another degree Celsius warming, and it will take major mitigation actions to stay even at that level rather than much higher. Thus, I believe increased hurricane intensities, melting glaciers, drying arid zones, increased wildfire incidence and commitments to some species extinctions and sea level rises are already inevitable. However, the number and intensity of such key vulnerabilities is dramatically reduced if we can keep the additional warming to no more than another degree or so Celsius, and it would be dramatically more dangerous if the warming is allowed to exceed an additional 2°C. Thus, for me, stabilizing the long-term levels of carbon dioxide equivalent concentrations in the atmosphere at 450 parts per million or less would trigger relative few additional dangerous events rather than allowing it to proceed as is now in motion toward 600 ppm or more, with many more dangerous risks.

The quickest way to summarize this complex issue based on a group consensus rather than my personal opinion, is to quote from the executive summary of the IPCC AR4 Chapter 19, Working Group II Report, of which I was a Coordinating Lead Author:

"General conclusions include [19.3]:

- Some observed key impacts have been at least partly attributed to anthropogenic climate change. Among these are increases in human mortality, loss of glaciers, and increases in the frequency and/or intensity of extreme events.
- Global mean temperature changes of up to 2°C above 1990–2000 levels would exacerbate current key impacts, such as those listed above (**), and trigger others, such as reduced food security in many low-latitude nations (*). At the same time, some systems such as global agricultural productivity, could benefit (o/*).
- Global mean temperature changes of 2° to 4°C above 1990–2000 levels would result in an increasing number of key impacts at all scales (**), such as widespread loss of biodiversity, decreasing global agricultural productivity and commitment to widespread deglaciation of Greenland (**) and West Antarctic (*) ice sheets.
- Global mean temperature changes greater than 4°C above 1990–2000 levels would lead to major increases in vulnerability (***), exceeding the adaptive capacity of many systems (***).
- Regions that are already at high risk from observed climate variability and climate change are more likely to be adversely affected in the near future due to projected changes in climate and increases in the magnitude and/or frequency of already-damaging extreme events."

Key to symbols: o,*,**,*** imply low, medium, high and very high confidence, respectively, in the conclusions as assessed by the Chapter 19 author team.

Q2. In your testimony you show a table which points out that at about a two to three degree centigrade temperature rise, there is a 50/50 chance that the ocean level will rise two to seven meters. But the WGI report suggests a rise of less than half a meter worst case. Why didn't you use this IPCC-accepted number in the table? Was the larger number vetted through the normal IPCC process?

A2. The WGII statement on which the testimony is based refers to long-term sea level rise, i.e., beyond the 21st century. The WGI table noted in your question refers to the 21st century sea level rise only. The risk of a two to seven meter sea level rise arises from the possibility of partial or total deglaciation of the Greenland ice sheet over the long-term, as indicated in Table 19.1 of Chapter 19, IPCC WGII.

This table is based on WGI Summary for Policy-makers and Chapters 6 and 10, and WGII section 19.3.5.3. The Summary for Policy-makers of the WGI report states:

> "Contraction of the Greenland ice sheet is projected to continue to contribute to sea level rise after 2100. Current models suggest ice mass losses increase with temperature more rapidly than gains due to precipitation and that the surface mass balance becomes negative at a global average warming (relative to pre-industrial values) in excess of 1.9 to 4.6°C. If a negative surface mass balance were sustained for millennia, that would lead to virtually complete elimination of the Greenland ice sheet and a resulting contribution to sea level rise of about 7 m. The corresponding future temperatures in Greenland are comparable to those inferred for the last interglacial period 125,000 years ago, when paleoclimatic information suggests reductions of polar land ice extent and 4–6 m of sea level rise." [6.4, 10.7]

In WGI Chapter 6, it is noted that Greenland contributed at least 2 m to sea level rise during the warm period 125,000 years ago, when polar temperatures were 3 to 5°C warmer than today. By combining information from models and paleoclimate data in the WGI report, WGII determined that warming of 1–4°C versus present entailed a risk of 2–7 m sea level rise over the long-term. That is the judgment reflected in Table 19.1.

Given the uncertainties in ice sheet modeling and paleoclimate data, WGII assessed confidence in this risk at "medium," i.e., about a 50–50 chance of being correct according to IPCC usage. WGI did not specifically assess the risk. WGII, as required by its Plenary Agreed Outline, took a risk-management approach and thus made a scientific judgment on the confidence that could be assigned to all major statements. Since risk is probability times consequences, and since risk-management requires estimates of likelihood, WGII thus met its obligations in that regard by considering confidence levels in the face of available scientific knowledge.

In plenary session in Brussels in April 2007, governments approved the following language that embodies the information in Table 19.1 of WGII:

> "Very large sea-level rises that would result from widespread deglaciation of Greenland and West Antarctic ice sheets imply major changes in coastlines and ecosystems, and inundation of low-lying areas, with greatest effects in river deltas. Relocating populations, economic activity, and infrastructure would be costly and challenging. There is medium confidence that at least partial deglaciation of the Greenland ice sheet, and possibly the West Antarctic ice sheet, would occur over a period of time ranging from centuries to millennia for a global average temperature increase of 1–4°C (relative to 1990–2000), causing a contribution to sea level rise of 4–6 m or more. The complete melting of the Greenland ice sheet and the West Antarctic ice sheet would lead to a contribution to sea-level rise of up to 7 m and about 5 m, respectively." [Working Group I Fourth Assessment 6.4, 10.7; Working Group II Fourth Assessment 19.3]

This text was approved by all governments after a debate in which the points raised above in response to your question were aired at the Plenary sessions.

Appendix 2:

Additional Material for the Record

More Trees, Less Global Warming, Right?—Not Exactly

Scientific American
APRIL 10, 2007

A 150-year simulation of worldwide deforestation finds that tropical forests are carbon sinks and boreal forests contribute to warming.

Before compact fluorescent light bulbs and ethanol, the first line of defense against global warming was planting trees.

Forests, after all, cool the atmosphere by drinking in carbon dioxide from the air. A new study, however, published in *Proceedings of the National Academy of Sciences* reports that forests' other climatic effects can cancel out their carbon cleaning advantage in some parts of the world. Using a three-dimensional climate model, the research team mimicked full global deforestation and also studied the effects of clear-cutting in different regions of latitude, such as the tropics and boreal zones. Apparently, these natural carbon sinks only do their job effectively in tropical regions; in other areas, they have either no impact or actually contribute to warming the planet. In fact, according to this model, by the year 2100, if all the forests were cut and left to rot, the annual global mean temperature would *decrease* by more than 0.5 degrees Fahrenheit.

"I'm not sure the slight amount of cooling is necessarily significant, but that removing all the forest produced little change" on temperature is, says study co-author Ken Caldeira, an ecologist at the Carnegie Institution of Washington's Department of Global Ecology in Stanford, Calif. "I think what's interesting is this global cancellation was a product of very different responses at different latitudes."

Trees perform three major climate functions: They absorb carbon, which they pull from the atmosphere, creating a cooling effect; their dark green leaves absorb light from the sun, heating Earth's surface; and they draw water from the soil, which evaporates into the atmosphere, creating low clouds that reflect the sun's hot rays (a mechanism known as evotranspiration that also leads to cooling). These three factors—the second two being largely ignored in climate models up to this point, according to Caldeira—taken together created very different results in the primary latitudes studied: the equatorial tropic zone; the mid-latitudes that include most of the U.S.; and the boreal areas, which are subarctic and include much of Canada, Russia and the northern extremities of the U.S.

In all three regions, forests dutifully perform their task of sucking carbon dioxide from the air, but light absorption and evotranspiration vary wildly. In tropical zones, forests have a significant, overall cooling effect. The soil is very wet and, so, via evotranspiration, the trees are covered by low-lying clouds that create a small albedo (power of light that is reflected by a surface). In non-tropical areas, Caldeira explains, "the real significant factor is whether there's snow on the ground in the winter." If a forest covers a snowy expanse, "that has a strong warming influence," he notes, because of little cloud cover resulting from less efficiency in evaporating water. The poor cloud formation coupled with the intense absorption of light by the trees "far overwhelms the cooling influence of the carbon storage," he says.

"In mid-latitudes, we got that it was basically a wash—the carbon dioxide effects were pretty much directly balanced by the physical effects," Caldeira says. He attributes this to the low contrast between light absorption from trees and from grass in pastures, though he notes that because there are some areas with wintry snow cover, the loss of a forest will probably have a slight, if any, cooling effect. He uses this example to point out the relative influence of the different forest functions. Whereas carbon levels can affect warming on a global scale, the effects of increased albedo and poor evotranspiration would affect temperatures only on a regional level. For instance, he says, "if you remove all the forest in the U.S., it would probably heat up the world, but have a slight cooling influence on the U.S., itself."

Navin Ramankutty, an Assistant Professor of Geography and Earth system sciences at McGill University in Montreal, says this study is the first to take a comprehensive look at the consequences of deforestation on the entire world. "You can't just blindly go ahead and reforest and that will tackle climate change," he says, pointing out a key finding in the study. "If you think about conservation groups, they're all talking about planting trees. We should be protecting tress for other reasons."

Caldeira agrees, saying that protecting the forest should be part of an effort to sustain the world's biodiversity. He also adds that the findings do not endorse clear-cutting or destroying wildlife habitats. "I think that it's important to look at preventing climate change as a means rather than an end in itself," he says. "Too narrow a focus on global warming and a loss of the broader focus of protecting life on this planet can lead to perverse outcomes." Rather than looking to forests to solve the current climate crisis by capturing carbon dioxide, he suggests targeting our "energy system," which continues to create the pollutant.

Why So Gloomy?

GUEST OPINION
BY RICHARD S. LINDZEN
SPECIAL TO *Newsweek*

April 16, 2007 issue—Judging from the media in recent months, the debate over global warming is now over. There has been a net warming of the earth over the last century and a half, and our greenhouse gas emissions are contributing at some level. Both of these statements are almost certainly true. What of it? Recently many people have said that the Earth is facing a crisis requiring urgent action. This statement has nothing to do with science. There is no compelling evidence that the warming trend we've seen will amount to anything close to catastrophe. What most commentators—and many scientists—seem to miss is that the only thing we can say with certainly about climate is that it changes. The Earth is always warming or cooling by as much as a few tenths of a degree a year; periods of constant average temperatures are rare. Looking back on the Earth's climate history, it's apparent that there's no such thing as an optimal temperature—a climate at which everything is just right. The current alarm rests on the false assumption not only that we live in a perfect world, temperature-wise, but also that our warming forecasts for the year 2040 are somehow more reliable than the weatherman's forecast for next week.

A warmer climate could prove to be more beneficial than the one we have now. Much of the alarm over climate change is based on ignorance of what is normal for weather and climate. There is no evidence, for instance, that extreme weather events are increasing in any systematic way, according to scientists at the U.S. National Hurricane Center, the World Meteorological Organization and the Intergovernmental Panel on Climate Change (which released the second part of this year's report earlier this month). Indeed, meteorological theory holds that, outside the tropics, weather in a warming world should be less variable, which might be a good thing.

In many other respects, the ill effects of warming are overblown. Sea levels, for example, have been increasing since the end of the last ice age. When you look at recent centuries in perspective, ignoring short-term fluctuations, the rate of sea-level rise has been relatively uniform (less than a couple of millimeters a year). There's even some evidence that the rate was higher in the first half of the twentieth century than in the second half. Overall, the risk of sea-level rise from global warming is less at almost any given location than that from other causes, such as tectonic motions of the Earth's surface.

Many of the most alarming studies rely on long-range predictions using inherently untrustworthy climate models, similar to those that cannot accurately forecast the weather a week from now. Interpretations of these studies rarely consider that the impact of carbon on temperature goes down—not up—the more carbon accumulates in the atmosphere. Even if emissions were the sole cause of the recent temperature rise—a dubious proposition—future increases wouldn't be as steep as the climb in emissions.

Indeed, one overlooked mystery is why temperatures are not already higher. Various models predict that a doubling of CO_2 in the atmosphere will raise the world's average temperature by as little as 1.5 degrees Celsius or as much as 4.5 degrees. The important thing about doubled CO_2 (or any other greenhouse gas) is its "forcing"—its contribution to warming. At present, the greenhouse forcing is already about three-quarters of what one would get from a doubling of CO_2. But average temperatures rose only about 0.6 degrees since the beginning of the industrial era, and the change hasn't been uniform—warming has largely occurred during the periods from 1919 to 1940 and from 1976 to 1998, with cooling in between. Researchers have been unable to explain this discrepancy.

Modelers claim to have simulated the warming and cooling that occurred before 1976 by choosing among various guesses as to what effect poorly observed volcanoes and unmeasured output from the sun have had. These factors, they claim, don't explain the warming of about 0.4 degrees C between 1976 and 1998. Climate modelers assume the cause must be greenhouse gas emissions because they have no other explanation. This is a poor substitute for evidence, and simulation hardly constitutes explanation. Ten years ago climate modelers also couldn't account for the warming that occurred from about 1050 to 1300. They tried to expunge the medieval warm period from the observational record—an effort that is now generally discredited. The models have also severely underestimated short-term variability El Niño and the Intraseasonal Oscillation. Such phenomena illustrate the ability of the complex and turbulent climate system to vary significantly with no external cause whatever, and to do so over many years, even centuries.

Is there any point in pretending that CO_2 increases will be catastrophic? Or could they be modest and on balance beneficial? India has warmed during the second half of the 20th century, and agricultural output has increased greatly. Infectious diseases like malaria are a matter not so much of temperature as poverty and public health policies (like eliminating DDT). Exposure to cold is generally found to be both more dangerous and less comfortable.

Moreover, actions taken thus far to reduce emissions have already had negative consequences without improving our ability to adapt to climate change. An emphasis on ethanol, for instance, has led to angry protests against corn price increases in Mexico, and forest clearing and habitat destruction in Southeast Asia. Carbon caps are likely to lead to increased prices, as well as corruption associated with permit trading. (Enron was a leading lobbyist for Kyoto because it had hoped to capitalize on emissions trading.) The alleged solutions have more potential for catastrophe than the putative problem. The conclusion of the late climate scientist Roger Revelle—Al Gore's supposed mentor—is worth pondering: the evidence for global warming thus far doesn't warrant any action unless it is justifiable on grounds that have nothing to do with climate.

Lindzen is the Alfred P. Sloan Professor of Meteorology at the Massachusetts Institute of Technology. His research has always been funded exclusively by the U.S. Government. He receives no funding from any energy companies.

THE STATE OF CLIMATE CHANGE SCIENCE 2007: THE FINDINGS OF THE FOURTH ASSESSMENT REPORT BY THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC), WORKING GROUP III: MITIGATION OF CLIMATE CHANGE

WEDNESDAY, MAY 16, 2007

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE AND TECHNOLOGY,
Washington, DC.

The Committee met, pursuant to call, at 10:05 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Bart Gordon [Chairman of the Committee] presiding.

BART GORDON, TENNESSEE
CHAIRMAN

RALPH M. HALL, TEXAS
RANKING MEMBER

U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE AND TECHNOLOGY
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Hearing on

The State of Climate Change Science 2007: The Findings of the Fourth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC), Working Group III: Mitigation of Climate Change

Wednesday, May 16, 2007
10 a.m. to 12 p.m.
2318 Rayburn House Office Building

Witness List

Dr. Mark Levine
Coordinating Lead Author, Chapter 6: Specific Mitigation Options in the Short and Medium Term – Residential/Commercial Sector

Dr. William Pizer
Lead Author, Chapter 11: Mitigation from a Cross-Sectoral Perspective

Mr. Stephen Plotkin
Lead Author, Chapter 5: Specific Mitigation Options in the Short and Medium Term – Transport and Infrastructure

Dr. Roger Pielke, Jr.
Professor, Environmental Studies at the University of Colorado and Director, Center for Science and Technology Policy Research

HEARING CHARTER

COMMITTEE ON SCIENCE AND TECHNOLOGY U.S. HOUSE OF REPRESENTATIVES

The State of Climate Change Science 2007: The Findings of the Fourth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC), Working Group III: Mitigation of Climate Change

WEDNESDAY, MAY 16, 2007
10:00 A.M.–12:00 P.M.
2318 RAYBURN HOUSE OFFICE BUILDING

Purpose

On May 16, 2007, the Committee on Science and Technology will hold a hearing on the third section of the 2007 Fourth Assessment Report, *Climate Change 2007: Mitigation of Climate Change,* prepared by Working Group III of the Intergovernmental Panel on Climate Change (IPCC). Released in Bangkok, Thailand, on May 4, 2007, the summary document highlights the key findings of the comprehensive appraisal of the current state of scientific knowledge on strategies to mitigate climate change. The full underlying report will be released later this year.

The Committee will hear testimony from three witnesses who will discuss the findings of the Report and current mitigation technologies and strategies.

Key Findings of the 2007 Working Group III Report

On May 4, 2007 the Intergovernmental Panel on Climate Change (IPCC) released the third section of its Fourth Assessment Report, entitled *"Mitigation of Climate Change."* This third section of the IPCC Fourth Assessment Report builds upon information contained in the previous reports. Working Group III analyzed mitigation options for the main economic sectors in the near-term and provided information on long-term mitigation strategies for various stabilization levels, paying special attention to implications of different short-term strategies for achieving long-term goals. Furthermore, the report addresses the relationship between mitigation and sustainable development. The Working Group was co-chaired by Dr. Ogunlade Davidson from Sierra Leone and Dr. Bert Metz from The Netherlands.

Held from April 30th through May 3rd, the 9th plenary session of Working Group III (WGIII) gathered government delegates from more than one hundred countries, together with the WGIII Lead Authors. The IPCC-produced documents, including this Summary for Policy-Makers (SPM), are consensus documents, meaning that all member governments approve the Summary documents and the underlying chapters before each document is released.

This report updates information from the Third Assessment Report based on research conducted over the past six years. Looking in detail at the most promising technologies for reining in heat-trapping gases, Working Group III's report outlines the need for improving energy efficiency in buildings, vehicles and appliances; shifting energy sources away from fossil fuels, retaining forests as a carbon sinks, and reducing emissions associated with agriculture.

Greenhouse Gas Emission Trends

Global greenhouse gas (GHG) emissions have grown since pre-industrial times and continue to grow. They increased by 70 percent between 1970 and 2004, and by 24 percent between 1990 and 2004. Growth in CO_2 emissions dominates the growth in greenhouse gases. The growth in emissions has come from all sectors with the greatest percentage increases coming from the energy supply, transport, and industry sectors.

Emissions associated with income and population growth have overwhelmed decreases in the amount of energy utilized per unit growth (energy intensity) and continue to drive growth in emissions. Under current climate change mitigation policies global GHGs will continue to grow over the next few decades. Current policies adopted have limited greenhouse gas emissions, but the scale of adoption is too small to counteract factors driving growth in emissions. Under scenarios assuming no new mitigation strategies are adopted, emissions will increase by 25–90 percent by 2030. Two thirds of these increases will come from the less developed countries.

Mitigation in the Short-Term (2007–2030)

Released earlier this year, the first two sections of the 2007 Fourth Assessment Report present a comprehensive appraisal of the current state of scientific knowledge of climate change and the impacts of that change on natural and human systems around the world.

The first two Working Groups presented information about the potential impacts associated with continued patterns of GHG emissions, making a strong case for mitigation. The report prepared by Working Group III focuses on options for mitigating climate change through a variety of technologies and policies. Some greenhouse-gas emissions can be cut through straightforward, cost-neutral measures such as improving insulation and replacing incandescent light bulbs with fluorescent lighting. Other techniques, such a Carbon Capture Storage (CCS), require substantial upfront funding, additional research, and a re-orientation of industry practices. Figure 1 illustrates the technologies and practices that Working Group III identifies as currently commercially available.

Figure 1: Key Mitigation Technologies and Practices Currently Commercially Available

Sector	Technology/ Practice
Energy Supply	Improved supply and distribution efficiency Switching from coal to gas Nuclear power Renewable heat / power (hydropower, solar, wind, geothermal, bio-energy) Combined heat / power Early application of Carbon Capture and Storage (CCS)
Transport	More fuel efficient vehicles Hybrid vehicles Cleaner diesel vehicles Biofuels Modal shifts from road transport to rail and public transport systems Non-motorized transport (cycling, walking) Land-use and transport planning
Building	Efficient lighting and day lighting More efficient electrical appliances, heating, and cooling devices Improved cook stoves Improved insulation Passive and active solar design for heating and cooling Alternative Refrigeration fluids Recovery and recycle of fluorinated gases
Industry	More efficient end-use electrical equipment Heat and power recovery Material recycling and substitution Control of non-CO_2 gas emissions Process-specific technologies
Agriculture	Improved crop and grazing land management to increase soil carbon storage Restoration of cultivated peaty soils and degraded lands Improved rice cultivation techniques Improved livestock and manure management to reduce CH_4 emissions Improved nitrogen fertilizer application techniques to reduce N_2O Dedicated energy crops to replace fossil fuel use Improved energy efficiency
Forests	Afforestation (converting open land into a forest by planting trees) Reforestation (restocking of existing, but depleted forests, with native trees) Forest management Reduced deforestation Harvested wood product management Use of forestry products for bio-energy to replace fossil fuel sources
Waste	Landfill methane recovery Waste incineration with energy recovery Composting of organic waste Controlled waste water treatment Recycling and waste minimization

Working Group II reported that global average temperature increases above two to four degrees Centigrade would lead to severe impacts in many parts of the world that could not be overcome by adaptation strategies. In order to avoid temperature increases in this range, atmospheric concentrations of carbon dioxide (CO_2) need to be stabilized in a range of 445–490 ppm.

Working Group III asserts it will be easier to reach and maintain a lower target stabilization range if mitigation efforts are undertaken early. This is because infrastructure built today has an associated energy demand that will go forward for the life of the infrastructure (25 years or more). If investments in infrastructure with high energy demand are made early, the opportunities for reducing GHG emissions going forward are constrained and it will be more difficult in the future to attain lower stabilization levels. The risk of severe climate change impacts increases with later implementation of mitigation strategies.[1]

Both bottom-up and top-down economic modeling studies indicate that there is a substantial economic potential for mitigation of global GHG emissions over the coming decades. However, macroeconomic cost estimates are sensitive to assumptions about rates of technological change, target stabilization level, and whether a multiple gas approach or carbon-only mitigation approach is adopted.

To stabilize GHG concentrations at a level that will avoid the most dangerous global warming, the Report estimates costs, generated by macroeconomic models, may vary from a reduction of three percent Gross Domestic Product (GDP) to an increase of one percent GDP. The reduction in GDP is greater for more stringent stabilization targets.

Another factor that influences macroeconomic cost estimates is the rate of technological change. Models that assume climate change policy enhances technological change, revenues from carbon taxes or auctioned permits are used to promote low-carbon technologies, or that assume a reform of existing taxation policies generally provide the lower macroeconomic cost estimates. Mitigation strategies that assumed a multiple-gas approach also resulted in substantially lower costs.

Not surprisingly, changes in lifestyle and behavior patterns of citizens across the world can contribute to climate change mitigation across all sectors. More wide spread adoption of existing mitigation practices can also have a positive role (Figure 1). New energy infrastructure investments in developing countries, upgrades of energy infrastructure in industrialized countries, and policies that promote energy security, can, in many cases, create opportunities to achieve GHG emission reductions compared to baseline scenarios. Additional co-benefits are country specific but often include air pollution abatement, balance of trade improvement, improvement of modern energy services to rural areas, and increases in employment opportunities.

Energy Supply

Investment in new energy supply infrastructure is estimated to be over 20 trillion dollars between now and 2030. The investments made in this time frame will impact GHG emissions for many years due to the expected lifespan of these facilities (25–50 years). A significant shift in energy supply to low-carbon technology is estimated to take decades even with aggressive incentives to promote them, but would result in a return to 2005 GHG emission levels by 2030 if the investment patterns were shifted to favor these technologies. The additional cost to achieve this shift is estimated to be small—on the order of five to ten percent more than investments in traditional energy supply technologies.

The pattern of investment will continue to be influenced by the market prices for fossil fuels. At higher fossil prices alternative energy sources will become more attractive, but other factors influence these decisions also. If higher fossil fuel prices lead to replacement of conventional oil resources with oil sands, oil shales, heavy oils, and synthetic fuels from coal and gas, GHG emissions will increase from this sector unless these facilities are equipped with carbon capture and sequestration systems.

Working Group III indicates that electricity generated through renewable energy sources could supply 30–35 percent of the total electricity supply in 2030. The Report concludes that nuclear energy will increase by two percent by 2030 (from 16 percent in 2005). High costs, safety, concerns about weapons proliferation and waste continue to constrain nuclear energy development.

Working Group III also found energy efficiency investments to be more cost-effective than increasing energy supply to meet energy demand. Efficiency improvements also deliver benefits in terms of energy security, pollution reduction, and employment.

[1] Pages 26 and 27 of the *Summary for Policy-makers.*

Transportation Sector

Pertaining to the transportation sector, multiple mitigation options exist, although these solutions must overcome many barriers, such as consumer preferences and lack of policy frameworks. Improved vehicle efficiency measures, leading to fuel saving, in many cases have net benefits but the market potential is much lower than the economic potential due to the influence of other consumer considerations, such as performance and size. It is important to note that Working Group III states that market forces alone, including rising fuel costs, are not expected to lead to significant emission reductions.

Depending on their production pathway, biofuels might play an important role in addressing GHG emissions in the transport sector. Biofuels used as gasoline and diesel additives/substitutes are projected to grow three percent of total transport energy demand in the baseline in 2030. This could increase to about 5–10 percent, depending on future oil and carbon prices, improvements in vehicle efficiency and the success of technologies to utilize cellulose biomass. Shifts in transportation use from cars to rail or public transport could provide great benefits to mitigated greenhouse gas emissions. This trend would further benefit from integrated urban planning to minimize the need for car travel.

Pertaining to air travel, medium-term mitigation potential for CO_2 from the aviation sector could be gained from improved fuel efficiency, which can be achieved through a variety of means including technology, operations, and air traffic management.

Residential & Commercial Building Sector

Energy efficiency options for new and existing buildings could considerably reduce CO_2 emission with net economic benefit. Many barriers exist against tapping this potential, but there are also large co-benefits. The barriers to achieving more energy efficient buildings are higher in developing countries. This is another area where rapid improvements in building design, development and diffusion of energy efficient building technologies (e.g., heating, cooling, lighting), adequate financing, and better information would yield benefits in reduced energy demand and GHG emissions. The rate of construction in developing countries is high and investments in this infrastructure will have an impact on emissions from these areas now and in the future. Working Group III estimated up to 30 percent of the GHG emissions could be avoided with net economic benefit by 2030.

Industrial Sector

The economic potential for reducing GHG emissions in the industrial sector is predominantly located in the energy intensive industries. The new facilities in developing countries include new technologies that are more energy efficient and are associated with lower GHG emissions. However, there are many old, inefficient facilities in both the developed and developing countries that, if upgraded, could significantly reduce GHG emissions from this sector. Key barriers to achieving reductions from this sector include the long life-span of existing facilities, lack of financial and technical resources, and insufficient access to technological information on strategies for emission reduction.

Agriculture and Forestry Sectors

Agricultural practices collectively can make a significant contribution at low cost to increasing soil carbon sinks, to GHG emissions reductions, and by contributing biomass feed stocks for energy use. The mitigation potential in the agricultural sector is associated primarily with opportunities to increase carbon sequestration and through reductions in methane and nitrous oxide emissions in specific agricultural systems.

Working Group III found that biomass can be an important energy feedstock. However, its contribution to mitigation is dependent upon a variety of factors including the demand for bioenergy from the transport and energy supply sectors, water availability, and competition with other land uses including production of food and fiber.

Similarly, forest-related mitigation activities can considerably reduce GHG emissions. Much of the mitigation potential from this sector is located in tropical regions and half of the potential could be achieved by reducing deforestation. Improved forest management practices could also result in increased CO_2 removal from the atmosphere and more sustainable systems with many co-benefits.

Mitigation in the Long-Term: Beyond 2030

As stated earlier, investment choices made in the 2005 to 2030 timeframe will determine the additional emissions reductions required in 2050 and beyond to stabilize atmospheric GHG concentrations at a level that will avoid dangerous impacts of climate change. Limited, preliminary results from analyses of costs and benefits associated with mitigating climate change indicate they are comparable.

In order to stabilize atmospheric concentrations of GHG, emissions would have to peak at some level and decline thereafter to achieve the new stabilized concentration. GHGs remain in the atmosphere for a long period of time once emitted and therefore achieving a lower stabilized concentration will not occur immediately once emissions are reduced. The current concentration of CO_2, the most important GHG is 379 ppm. Working Group III found that the stabilization levels they examined are achievable if currently available technologies and the technologies expected to be commercialized by 2030 are deployed. The technologies and practices predicted to be available by 2030 are listed in Figure 2.

Decision-making about appropriate level of global mitigation over time involves an iterative risk management process that includes mitigation and adaptation, taking into account actual and avoided climate change damages, co-benefits, sustainability, equity, and attitudes to risk. Choices about the sale and timing of GHG mitigation involve balancing the economic costs of more rapid emissions reductions now against the corresponding medium-term and long-term climate risks of delay.

The preferred choice rests on the assumption about the shape of the damage cost curve associated with increased global average temperature and on the sensitivity of the climate to continuing increases of GHG emissions. If the relationship between climate change and the costs associated with damaging impacts is gradually rising and the changes are predictable and regular in their growth, this would allow for greater adaptation and would economically justify a later starting date for implementing mitigation measures.

If however, the costs associated with climate change increase rapidly with time and if the rates of change are not predictable or stable, then earlier and more stringent mitigation strategies are required. Even small probabilities of catastrophic events such as significant melting of ice sheets in Greenland or Antarctica would justify earlier and more stringent action.

If climate sensitivity is high, earlier and more stringent implementation of mitigation is required than if climate sensitivity is low. The results from Working Group II, indicating more rapid and widespread impacts being identified over the past decade suggest the climate sensitivity may be high, especially if GHG emissions continue to grow.

Figure 2: Key Mitigation Technologies and Practices Expected to Be Available in 2030

Sector	Technology/ Practice
Energy Supply	Carbon Capture and Storage (CCS) for gas, biomass and coal-fired facilities Advantaged nuclear power Advantaged renewable energy (tidal and wave, solar, and solar photo voltaic)
Transport	Second generation biofuels High efficiency aircraft Advanced electric and hybrid vehicles
Building	Integrated design of commercial buildings including intelligent metering and control Solar PV integrated in buildings
Industry	Advanced energy efficiency CCS for cement, ammonia, and iron manufacturing Inert electrodes for aluminum manufacture
Agriculture	Improved crop yields
Forests	Tree species improvement to increase biomass productivity and carbon sequestration Improved remote sensing technologies for analysis of vegetation/ soil carbon sequestration potential and mapping land use changes
Waste	Bio-covers and bio-filters to optimize CH_4 oxidation

Policies, Measures, and Instruments to Mitigate Climate Change

A wide variety of national policies and instruments are available to governments to create the incentives for mitigation actions. Their applicability depends on national circumstances and understanding their interactions, but experience from implementation in various countries and sectors shows there are advantages and disadvantages for any given instrument. Policies that provide a real or implicit price of carbon could create incentives for producers and consumers to significantly invest in low-GHG products, technologies and processes. Such policies could include economic instruments, government funding and regulation.

Voluntary agreements between governments and industry and voluntary actions being adopted by corporations, non-governmental organizations, local and regional authorities and other groups may limit GHG emissions and stimulate innovative policies, but they have had limited impact on national or regional emission levels and have not resulted in significant reductions of GHG emissions.

Government support through financial contributions, tax credits, standard setting and market creation is important for effective technology development countries depends on enabling conditions and financing. Figure 3 illustrates possible government actions noted by Working Group III.

Figure 3: Environmentally Effective Polices, Measures, and Instruments

Sector	Policies, Measures and Instruments	Key constraints or opportunities
Energy Supply	- Reduction of fossil fuel subsidies - Taxes or carbon charges on fossil fuels	Resistance by vested interests may make them difficult to implement
	- Feed-in tariffs for renewable energy technologies - Renewable energy obligations - Producer subsidies	May be appropriate for countries that are building up their transportation systems
Transport	Mandatory fuel economy, biofuel blending and CO2 standards for road transport	Partial coverage of vehicle fleet may limit effectiveness
	Taxes on vehicle purchase, registration, use and motor vehicles	Effectiveness may drop with higher incomes
	- Influence mobility needs through land use regulations, and infrastructure planning -Investment in attractive public transport facilities and non-motorized forms of transport	Particularly appropriate for countries that are building up their transportation systems
Buildings	Appliance standards and labeling	Periodic revision of standards needed
	Building codes and certification	Attractive for new buildings but enforcement can be difficult
	Demand-side management programs	Need for regulations so that utilities may profit
	Public sector leadership programs	Government purchasing can expand demand for energy-efficient products
	Incentives for energy service companies	Access to third party financing is crucial
Industry	- Provision of benchmark information - Performance Standards - Subsidies, tax credits	May be appropriate to stimulate technology uptake. Stability of national policy important in view of international competitiveness
	Tradable permits	Predictable allocation mechanisms and stable price signals important for investments
	Voluntary agreements	Success factors include: clear targets, a baseline scenario, third party involvement, and cooperation between government and industry
Agriculture	Financial incentives and regulations for improved land management, maintaining soil carbon content, efficient use of fertilizers and irrigation	May encourage synergy with sustainable development with reducing vulnerability to climate change
Forestry	- Financial incentives (national and international) to increase forest area, to reduce deforestation, and to maintain and manage forests - Land use regulation and enforcement	Constraints include lack of investment capital and land tenure issues. Can help poverty alleviation.
Waste Management	Financial incentives for improved waste and wastewater management	May stimulate technology diffusion
	Renewable energy incentives or obligations	Local availability of low-cost fuel
	Waste management regulations	Most effectively applied at national level with enforcement strategies

Witnesses

Dr. Mark Levine, Division Director of the Environmental Energy Technologies Division at Lawrence Berkeley National Laboratory (LBNL)

Dr. Mark Levine served as a Coordinating Lead Author for Chapter 6 of the report entitled: *Specific Mitigation Options in the Short- and Medium-Term—Residential/Commercial Sector (Including Services).* Currently, Dr. Levine works as division director of the Environmental Energy Technologies Division at Lawrence Berkeley National Laboratory (LBNL). He received his Ph.D. in chemistry from UC–Berkeley and was a Fulbright scholar in Germany. Before joining LBNL in 1978, he was a staff scientist at the Ford Foundation Energy Project in Washington, D.C., and a senior energy policy analyst at SRI, International in Menlo Park. Dr. Levine research focuses on energy modeling, appliance energy efficiency policy, and other aspects of energy efficiency and climate change policy analysis. He sits on the boards of several energy policy organizations, including the American Council for an Energy-Efficient Economy and the Center for Clean Air Policy.

Dr. William A. Pizer, Fellow at Resources for the Future and a Senior Economist at the National Commission on Energy Policy

Dr. William Pizer served as a Lead Author for Chapter 11 of the report entitled: *Mitigation from a Cross-Sectoral Perspective.* Currently, Dr. Pizer is a Fellow at Resources for the Future and Senior Economist at the National Commission on Energy Policy. Dr. Pizer has a B.A. in physics from the University of North Carolina at Chapel Hill and a Ph.D. and M.A. in economics from Harvard University. Dr. Pizer's research seeks to quantify how various features of environmental policy and economic context, including uncertainty, individual and regional variation, technological change, irreversibility, spillovers, voluntary participation, and flexibility, influence a policy's efficacy.

Recently, Dr. Pitzer's work has considered the regional variation in household energy use, firm variation in pollution control costs, the effectiveness of voluntary programs, the role of technology programs in pollution control efforts, the relative efficiency of flexible performance standards and intensity targets, and the effectiveness of regional climate change policies. Since August 2002, Dr. Pizer has worked part-time as a Senior Economist at the National Commission on Energy Policy. During 2001–2002, he served as a Senior Economist at the President's Council of Economic Advisers where he worked on environment and climate change issues.

Mr. Steven Plotkin, Transportation Energy and Environmental Systems Analyst at the Center for Transportation Research, Argonne National Laboratory

Mr. Stephen Plotkin served as a Lead Author for Chapter 5 of the report entitled: *Specific Mitigation Options in the Short- and Medium-Term—Transport and Infrastructure.* Mr. Plotkin is a transportation energy analyst with the Center for Transportation Research of the Argonne National Laboratory. His recent work focuses on advanced automotive technology, greenhouse gas reduction strategies, and automotive fuel economy policy. He was a co-principal investigator of the joint U.S. Department of Energy/Natural Resources Canada study, *Examining the Potential for Voluntary Fuel Economy Standards in the United States and Canada* and a consultant to the National Research Council's study on the effectiveness and impact of Corporate Average Fuel Economy (CAFE) Standards. Mr. Plotkin received B.S. in Civil Engineering from Columbia University and his Masters in Aerospace engineering and did graduate work in applied physics/aerospace engineering at Cornell University.

Dr. Roger Pielke, Jr., Director, Center for Science and Technology Policy Research and Professor in the Environmental Studies Program at the University of Colorado

Dr. Roger Pielke is a Professor in the Environmental Studies Program and also Director, Center for Science and Technology Policy Research. With a B.A. in mathematics and a Ph.D. in political science from the University of Colorado, he focuses his research on the relation of scientific information and public and private sector decision-making. His current areas of research are societal responses to extreme weather events, domestic and international policy responses to climate change, and United States science policy. Dr. Pielke's research interests include understanding natural disasters and climate change, the politicization of science and decision-making under uncertainty.

Definitions

Mitigation Potential: The concept has been developed to assess the scale of GHG reductions that could be made, relative to emissions baselines, for a given level of carbon price (expressed in terms of cost per unit of carbon dioxide equivalent emissions avoided or reduced). Mitigation potential is further differentiated in terms of "market potential" and "economic potential."

Market Potential: The mitigation potential based on private costs and private discount rates, which might be expected to occur under forecast market conditions, included policies and measures currently in place, noting that barriers limit actual uptake.

Economic Potential: The mitigation potential, which takes into account social costs and benefits and social discount rates, assuming that market efficiency is improved by policies and measures and that barriers are removed.

Bottom-Up versus Top-Down Studies: Bottom-up studies look at mitigation options emphasizing specific technologies and regulations. In contrast, top-down studies assess the economy-wide potential of mitigation options. Bottom-up studies are useful for the assessment of specific policy options a sectoral level, while top-down studies better assess cross-sectoral and economy-wide climate change policies, such as carbon taxes and stabilization policies.

Greenhouse Gases: Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6). Water vapor is also a greenhouse gas—the most abundant greenhouse gas in the atmosphere. However, the concentration of water vapor in the atmosphere has not been significantly altered through human activities unlike the other above-mentioned greenhouse gases which are associated with fossil fuel production and use, land-use management and change, and industrial processing and consumer products.

Chairman GORDON. This hearing will come to order, and good morning, everyone. Welcome to the Committee's third hearing on the Intergovernmental Panel on Climate Change, Fourth Assessment Report. On May the 4th the third Working Group released a summary of its chapters on the mitigation of Climate Change in Bangkok. The summaries of the Working Group I and II released earlier this year indicated that both adaptation and mitigation strategies are needed to counteract the effects of increasing greenhouse gas concentration in the atmosphere.

Adaptation strategies can lessen the impact of the challenges in climate, changes in climate we are experiencing now and that we will experience under any scenario in the future. However, the IPCC report tells us that if we are to avoid the dangerous impacts of climate change associated with global temperature increases of four degrees or higher, we must develop and implement mitigation strategies.

Working Group III's report outlines specific measures that we can consider to design a path to stabilize and then reduce greenhouse gas emissions. Some are policy measures, others are technological. Not surprising, the report counsels that the earlier we begin the better chance we have of achieving the goal of avoiding dangerous impacts of climate change.

Of course, we are all concerned about the cost of achieving this goal. As we all suspect, this effort will be costly, and the estimates of these costs vary considerably depending upon the assumption used in the economic models to generate them. However, in action is not cost free, either in monetary terms or in human suffering. Longer, more intense droughts increase flooding and accelerated sea level rise are all very costly. Increased public health problems and increased mitigation of environmental refugees are also very costly as the Pentagon recently pointed out.

While there will be costs, there will also be benefits and opportunities for new jobs and new industries. We simply cannot afford the cost of inaction, especially when we consider our need to move to a new generation future to achieve greater national and economic superiority.

The summary does not point to any single policy or group of technologies that will achieve emission reductions. Each nation and each region must participate in a global effort to reduce emissions by developing strategies that will work within their respective economic and social frameworks.

We must do the—for the U.S. the types of analysis performed by the IPCC for a global basis to understand the cost and benefits associated with alternative mitigation policies and technologies. Time is the one thing we can never recover.

We have an opportunity if we act now to avoid radical alternations in our world that we will be unable to adapt to or to overcome. We have an obligation to our children and grandchildren to face the challenge of climate change and deliver them a future that is an energy security as as we inherited. We can only accomplish that by diversifying our energy supplies and becoming more energy efficient.

We have the opportunity to lead the world in cooperative effort to make sustainable development not just a goal but a reality. The sooner we begin, the better off we will be.

We have a distinguished panel of witnesses here this morning to discuss the options of mitigating climate change. Welcome to all of you, and thank you for being here today to discuss this important topic with the Committee.

[The prepared statement of Chairman Gordon follows:]

PREPARED STATEMENT OF CHAIRMAN BART GORDON

Good morning and welcome to the Committee's third hearing on the Intergovernmental Panel on Climate Change's Fourth Assessment Report.

On May 4, the third Working Group released the Summary of its chapters on the Mitigation of Climate Change in Bangkok. The Summaries of Working Groups I and II released earlier this year indicated that both adaptation and mitigation strategies are needed to counteract the effects of increasing greenhouse gas concentrations in the atmosphere.

Adaptation strategies can lessen the impacts of the changes in climate we are experiencing now and that we will experience under any scenario in the future. However, the IPCC reports tell us that if we are to avoid the dangerous impacts of climate change associated with global temperature increases of four degrees or higher, we must develop and implement mitigation strategies.

Working Group III's report outlines specific measures that we can consider to design a path to stabilize, and then reduce, greenhouse gas emissions. Some are policy measures, others are technological. Not surprising, the report counsels that the earlier we begin the better chance we will have of achieving the goal of avoiding dangerous impacts of climate change.

Of course, we are all concerned about the costs of achieving this goal. As we all suspect, this effort will be costly and the estimates of these costs vary considerably depending upon the assumptions used in the economic models to generate them.

However, inaction is not cost-free, either in monetary terms or in human suffering. Longer, more intense droughts, increased flooding, and accelerated sea level rise are all very costly. Increased public health problems and increased migration of environmental refugees are also very costly.

While there will be costs, there will also be benefits and opportunities for new jobs and new industries. We simply cannot afford the costs of inaction, especially when we consider our need to move to new energy future to achieve greater national and economic security.

The Summary does not point to any single policy or group of technologies that will achieve emission reductions. Each nation and each region must participate in a global effort to reduce emissions by developing strategies that will work within their respective economic and social frameworks.

We must do for the U.S., the types of analyses performed by the IPCC on a global basis, to understand the costs and benefits associated with alternative mitigation policies and technologies.

Time is the one thing we can never recover. We have an opportunity, if we act now, to avoid radical alterations in our world that we will be unable to adapt to or overcome. We have an obligation to our children and grandchildren to face the challenge of climate change and deliver them a future that is as energy secure as the one we inherited. We can only accomplish that by diversifying our energy supplies and becoming more energy efficient.

We have an opportunity to lead the world in a cooperative effort to make sustainable development not just a goal, but a reality. The sooner we begin, the better off we will be.

We have a distinguished panel of witnesses here this morning to discuss the options for mitigating climate change. Welcome to all of you, and thank you for being here today to discuss this important topic with the Committee.

Chairman GORDON. At this time I am pleased to yield to distinguished Ranking Member Mr. Hall, for an opening statement.

Mr. HALL. I thank you, Mr. Chairman, and I am really pleased that you are holding this hearing today, because it provides all of us with an opportunity to discuss what I believe and others of us believe this committee should focus on when it comes to the issue of global climate change and how much it is going to cost and what do we get in return.

The key question I think facing all of us here in Congress is not what does the latest science say about climate change. The key question is given all the science what is the appropriate policy for the United States to move our Nation towards affordable, and I repeat again, affordable, reliable, and clean energy sources.

It is not an easy question to answer. We have to consider if the U.S. regulates greenhouse gases what impact could we have on other major carbon-emitting countries who do not follow suit. Would this reality put America in the position of shouldering the burden of cleaning up the world and having our citizens bear the high cost? What would regulations mean for the price of natural gas, for example, for electricity rates? Are these costs we are willing to accept if given the uncertainty about whether regulations could help them? Do you think we would accept them?

When I return to my Congressional district, constituents have high on their list the high cost of gasoline. We need to be looking to ways to lower this cost, not raise it, and yet the scenarios being discussed here today propose raising the price of gasoline substantially. Estimates of price increases range from 20 cents per gallon to as much as a dollar per gallon. Rather than focusing on ways to raise energy prices for Americans, we ought to be discussing what the United States could accomplish with the right investments in energy research and energy development. We have to consider the enormous benefits and the cost of adaptation, and we must not lose sight of other pressing national priorities and understand the overall burden of all the national needs to the average citizen.

Work Group III was asked to look at ways to mitigate greenhouse gases, and that is what they did. I think their charge was too narrow and should have included a more comprehensive assessment to help us answer the questions I mentioned earlier. Policymakers should not make decisions in a vacuum, and so it would be more useful if the technical information presented to us was placed in a broader context.

Nevertheless, they did what they did under the charge that they were given. The Working Group III report points out that even a middle of the road greenhouse gas mitigation approach would mean a reduction of up to four percent of global GDP.

Let me place that in context for you. At the end of the first quarter of 2007, the U.S. GDP was $13.6 trillion. Four percent of that is $544 billion. Now, remember that figure, $544 billion. By comparison total United States spending on defense in FY 2004, was $567 billion, just a little bit over the four percent that I am asking you to compare with.

The American Competitiveness Initiative when complete in FY 2016, will total only $19 billion, just a fraction of one percent of the U.S. GDP. One hundred and forty-three billion is the total Federal R&D investment in FY 2007. Nationwide education spending, for federal, State, and local combined as a percent of GDP is 5.7 percent.

Finally, the entire budget for the Social Security Administration is on the order of $600 billion. Now, compare those, and what do you think of those comparisons?

Mr. Chairman, now that all three groups of the IPCC have reported, I look forward to the real discussion that the Committee should promote. We should be the leader in the House of Representatives for promoting wise investments in energy research and development, investments that tap into America's innovative spirit, and lead us to a future where our energy supply is affordable, reliable, and clean, and I add again affordable.

I yield back the balance of my time.

[The prepared statement of Mr. Hall follows:]

PREPARED STATEMENT OF REPRESENTATIVE RALPH M. HALL

Thank you Mr. Chairman. I am glad that you are holding this hearing today because it provides all of us with an opportunity to discuss what I believe this committee should focus on when it comes to the issue of global climate change—how much is it going to cost and what do we get in return.

The key question facing all of us here in Congress is not "What does the latest science say about climate change?" The key question is "Given all the science, what is the appropriate policy for the United States to move our nation towards affordable, reliable and clean energy sources?" It is not an easy question to answer. We must consider if the U.S. regulates greenhouse gases, what impact could we have if other major carbon emitting countries do not follow suit? Would this reality put America in the position of shouldering the burden of cleaning up the world and having our citizens bear the high costs? What would regulations mean for the price of natural gas? For electricity rates? Are these costs we are willing to accept given the uncertainty about whether regulations could help?

When I return to my congressional district, constituents have high on their list of concerns the high price of gasoline. We need to be looking at ways to lower this cost, not raise it. And yet, the scenarios being discussed today propose raising the price of gasoline substantially. Estimates of price increases range from 20 cents per gallon to as much as $1.00 per gallon.

Rather than focusing on ways to raise energy prices for Americans, we must discuss what the U.S. could accomplish with the right investments in energy research and development. We must consider the enormous benefits and lower costs of adaptation. And, we must not lose sight of other pressing national priorities and understand the overall burden of all national needs on the average citizen.

Working Group III was asked to look at ways to mitigate greenhouse gases, and that's what they did. I think their charge was too narrow and should have included a more comprehensive assessment to help us answer the questions I mentioned earlier. Policy-makers should not make decisions in a vacuum, and so it would be more useful if the technical information presented to us was placed in a broader context. Nevertheless, they did what they did under the charge given to them.

The Working Group III report points out that even a middle of the road greenhouse gas mitigation approach would mean a reduction of up to four percent of global GDP. Let me place that in context for you. At the end of the first quarter of 2007, the U.S. GDP was $13.6 trillion. Four percent of that is $544 billion. By comparison:

- Total U.S. spending on defense in FY 2007 ($567 billion) will be close to four percent of U.S. GDP.
- The American Competitiveness Initiative, when complete in FY 2016, will total $19.5 billion, just a fraction of one percent of U.S. GDP.
- $143 billion is the total Federal R&D investment in FY 2007.
- Nationwide education spending (federal, State and local combined) as a percent of GDP is 5.7 percent.
- Finally, the entire budget for the Social Security Administration is on the order of $600 billion.

Mr. Chairman, now that all three groups of the IPCC have reported, I look forward to the real discussion this committee should promote. We should be the leader in the House of Representatives for promoting wise investments in energy research and development, investments that tap into American's innovative spirit and will lead us to a future where our energy supply is affordable, reliable and clean.

I yield back the balance of my time.

Chairman GORDON. Thank you, Mr. Hall, and I just want to remind you that out of the Subcommittee this week we passed the ARPA–E bill. We will have an opportunity to carry out your wishes next week when the ARPA–E bill will be on, which will be the most cutting-edge effort to do that kind of technology investment at, as you pointed out, a very modest way.

Yes, sir, Mr. Hall. Did you——

Mr. HALL. I respect you and respect your position, and I look forward to next week.

Chairman GORDON. Thank you, sir. And if there are Members who wish to submit additional opening statements, your statements will be added to the record.

[The prepared statement of Mr. Costello follows:]

PREPARED STATEMENT OF REPRESENTATIVE JERRY F. COSTELLO

Good morning. I want to thank Chairman Gordon for holding today's hearing on the third section of the 2007 Fourth Assessment Report, *Climate Change 2007: Climate Change Impacts, Adaptation and Vulnerability,* prepared by Working Group III of the Intergovernmental Panel on Climate Change (IPCC). The report offers key findings of the current state of scientific knowledge on strategies to mitigate climate change and provides Congress with additional information on global warming.

As Congress begins to develop legislation to address climate change, we cannot ignore the reality that coal is going to play a role in our nation's energy supply and the world energy supply for years to come. Coal generates half of the electricity in this country and is a reliable domestic source of power with a 250-year supply of coal in the U.S. alone. To fully maximize our use of coal, we must continue to take steps that reduce emissions. The only way to achieve this goal is through advancements in technology. I have been a strong supporter of clean coal initiatives and programs to advance the research and development needed to improve coal-based electricity generation. Congress must continue to support the clean coal programs in the President's FY08 budget, which includes the FutureGen Project, slated to be the world's first zero-emissions coal plant. Among other things, FutureGen will demonstrate the ability to sequester carbon dioxide emissions safely underground. The more coal plants using clean coal technology equals reduced greenhouse gas emissions.

Clean coal technologies do exist; however, they need the support and backing from Congress to further develop and demonstrate their commercial viability. As we consider climate change legislation, I encourage my colleagues to include coal as part of our energy solution. Again, I look forward to working with my colleagues as we find practical solutions that lead us down the path of energy independence and protection of our environment.

I welcome the panel of witnesses and look forward to their testimony.

[The prepared statement of Ms. Johnson follows:]

PREPARED STATEMENT OF REPRESENTATIVE EDDIE BERNICE JOHNSON

Thank you, Mr. Chairman. I would like to welcome today's witnesses to our hearing on the third section of the Intergovernmental Panel on Climate Change 2007 Fourth Assessment Report.

Entitled, *"Climate Change 2007: Mitigation of Climate Change,"* the report was prepared by Working Group III of the IPCC.

Mr. Chairman and colleagues, you may know that I chair the Subcommittee on Water Resources and Environment, of the House Transportation Committee.

This position places me at the intersection of water resources and the environment's sensitivity to climate change.

Texas' growing population is putting stress on the quality and effects of its precious water resources.

The Environmental Protection Agency estimates that Texas could see a temperature increase by four degrees Fahrenheit by 2100 if we continue along the predicted global warming path.

The result, Mr. Chairman, will be hotter, drier Texas summers, with greater threats of severe wildfires. Droughts will worsen and flooding will become more of an issue. Rising sea levels may affect people and animals living near the coastal zones.

The E.P.A. itself estimates that it could cost up to $12.9 billion to protect the Texas coast from a 20-inch rise in sea level.

There are other effects predicted for Texas as well, such as a loss of its brown shrimp population and shrinking barrier islands.

Mr. Chairman, it is disturbing to know that these climate changes have resulted from human activities, and further damage is on the horizon.

Today's witnesses will present the summary of a large volume of scientific information from delegates from more than one hundred nations.

Importantly, the report provides mitigation options for the main economic sectors in the near-term and also provides information on long-term mitigation strategies.

The report also discusses the implications of different short-term strategies for achieving long-term goals.

It is my hope that this information will better inform policy-makers so that we can spur change.

Again, welcome to today's witnesses. Thank you, Mr. Chairman. I yield back.

Chairman GORDON. And at this time I would like to introduce our witnesses. First, Dr. Mark Levine served as the Coordinating Lead Author for Chapter 6, *Specific Mitigation Options in the Short- and Medium-Term—Residential and Commercial Sector* of the Working Group III report. Currently Mr. Levine works as the Division Director of the Environmental Energy Technology Division at Lawrence Berkeley Laboratory.

Our next witness will be Dr. William Pizer. He served as the Lead Author for Chapter 11, *Mitigation from a Cross-Sectoral Perspective* of the Working Group III report. Dr. Pizer is a fellow at Resources for the Future and senior economist at the National Commission on Energy Policy.

Dr.—or rather Mr. Steven Plotkin served as the Lead Author of Chapter 5 of the report entitled, *Specific Mitigation Options in the Short- and Medium-Term—Transport and Infrastructure.* Mr. Plotkin is a transportation energy analyst with the Center of Transportation Research at the Argonne National Laboratory.

And finally, Dr. Roger Pielke, Jr. is Professor of Environmental Studies Program at the University of Colorado and Director of the Center for Science and Technological Policy Research.

As our witnesses should know that we try to limit our spoken testimony to five minutes, but this is an important hearing, and we want you to be judicious but to take what time you need, and we will start with Dr. Levine. Thank you for being here.

STATEMENT OF DR. MARK D. LEVINE, DIVISION DIRECTOR OF THE ENVIRONMENTAL ENERGY TECHNOLOGY DIVISION AT LAWRENCE BERKELEY LABORATORY

Dr. LEVINE. Thank you, Mr. Chairman, and distinguished Members of the Committee. I greatly appreciate your holding this hearing on this important topic. I am honored to be here today to speak to you.

As you pointed out, I am a senior staff scientist at Lawrence Berkeley National Laboratory, former division director, but I speak to you in my capacity as Coordinating Lead Author of Chapter 6 of Working Group III of the 4th assessment report.

I was asked to address two questions. The first was to describe to you the findings from Chapter 6, Specific Mitigations in the Short- and Medium-Term for Residential and Commercial Buildings, and second, to explain how these findings differ from previous assessments.

I think this chapter is particularly interesting in light of the opening comments that we have heard because buildings represent an opportunity to reduce, to mitigate carbon dioxide emissions cost effectively, so that, in fact, the concern that you may have about impacts on the economy need not be concerns if one does energy efficiency cost effectively and there are numerous opportunities to do so in the building sector.

The Summary for Policy-makers notes that energy efficiency options for new and existing buildings should considerably reduce CO_2 emissions with net economic benefits. It goes on to estimate that by 2030 one could achieve 30 percent reduction in emissions due to energy use associated with buildings if one were able to tap into all cost-effective measures. Of course, tapping into all these measures is no easy job, and the report points out the numerous barriers that exist to obtaining these measures in the marketplace. It also notes that it is particularly difficult for many developing countries to overcome the many barriers to energy efficiency in buildings.

Let me make a few comments on the findings. The most, there are several significant features of this report. The first is that the full report of 90 pages underwent extensive review by Governments, by experts, and so I view the report as as authoritative review of the literature as one can find, far more than my colleagues and I could ever have accomplished. It is a long and torturous process at the IPCC, but it does give quality and works very hard to remove bias.

My second comment has to do with the contribution of the report to reviewing the different bottom-up studies of energy efficiency potential in buildings. By bottom-up I mean a characterization of the key technologies that can reduce carbon dioxide emissions, their costs, and the quantity of emission reductions that can be achieved through time. The analysis involved a review of 80 studies and a thorough assessment of 17 of these. These studies covered the globe. This is the first time that a thorough analysis of these types of studies have ever been done, and this analysis gives me confidence that we are working on a body of literature that is, in fact, meaningful. I have been troubled for many years working in the field, not knowing what really was understood out there in work carried out in many other countries. So this, I think, is a significant achievement.

Second observation from the study is that this 30 percent reduction, if you could achieve it, is comparable to a 30 percent increase that would be projected in the lowest of the scenarios that we are looking at and comparable to about a 45 percent increase in a typical scenario that we are looking at. So that it is within the realm of the possible that this cost-effective potential, a potential, Mr. Hall, that would not for the case of buildings, cause damage to the economy, could be achieved without increasing emissions. But, of course, it depends on the scenario itself, and those results would be less significant if the scenario is higher.

On the other hand, it is important to note that 70 percent of electricity is used in buildings, and as we decarbonize electricity, that reduces emissions from buildings. Now, there you get into carbon charges. If you want to decarbonize electricity, then it is likely that you will have to talk about certain carbon charges.

Finally, I want to observe that notwithstanding these opportunities the policies necessary to bring about these major reductions are very substantial, and the study identified many policies that were, in fact, quite effective in different places, but it did not identify any silver bullets, any policies that were effective broadly, but it did show quite a number of effective policies.

Now, I have spent most of my time I think. Let me conclude with your last question. How does this compare with the previous assessments? The third assessment report devoted very little attention to this topic, so I almost want to skip it except that it came up with some estimates that said, well, we could, in fact, achieve emissions at 1998, levels in 2010, 2020, and 2050, but those were admittedly guesses of the team. And so we give them low evidence and low agreement in our terminology for how much we, how much credibility we want to place on those results. And that is about it for that report.

In the second assessment report these was a thorough descriptive description of technologies, a description of policies but no evaluation, and the reason for that was that the world hadn't moved toward energy efficiency far enough at that point to be able to do evaluation.

But I think my final, my major conclusion is that the world has come a long way. There is really no contradiction among the assessment, but we have seen an evolution of knowledge over time as different countries, different regions, different, indeed, different cities, have implemented different policies and different technologies for a greenhouse gas mitigation in the building sector.

Thank you very much.

[The prepared statement of Dr. Levine follows:]

PREPARED STATEMENT OF MARK D. LEVINE

Introduction

Mr. Chairman and distinguished Members of the Committee, thank you for holding this important hearing. It is my honor to be here today and I hope that I can be helpful to you and your staff as the Committee considers the findings of the report and work to address its policy implications.

My name is Mark Levine and I am a senior scientist at the Lawrence Berkeley National Laboratory and formerly the Division Director for the Lab's Environmental Energy Technologies Division. However, my testimony here today is not on behalf of the Laboratory, but rather as a participant in the IPCC Working Group III on mitigation.

I was the Convening Lead Author for the Second Assessment Report for the Chapter on GHG emissions on buildings and was the Co-coordinating Lead Author for the 4th Assessment for the same topic (with Professor Diana Urge-Vorsatz of the Central European University, Hungary). I am testifying in this role, on my own behalf and as a result of my expertise in this role.

The Committee has asked me address two issues. First, to discuss the findings from Chapter 6, *Specific Mitigations in the Short- and Medium-Term—Residential/Commercial Sector.* And, second, to explain how the findings of this Fourth Assessment report differ from those of the previous *Assessments of Mitigation of Climate Change.*

I am interpreting the second question narrowly, as it relates to Chapter 6—the area of my direct expertise.

Major findings of Chapter 6

The highest level findings from Chapter 6 are contained in the Summary for Policy-Makers (SPM). The SPM notes that "energy efficiency options for new and existing buildings could considerably reduce CO_2 emissions with net economic benefit." It goes on to state that "(m)any barriers exist against tapping this potential, but there are also large co-benefits *(high agreement, much evidence)*." In summary the working group found that:

- By 3030, about 30 percent of the projected GHG emissions in the building sector can be avoided with net economic benefit
- Energy efficient buildings, while limiting CO_2 can also improve indoor and outdoor air quality, improve social welfare and enhance energy security
- Opportunities for realizing GHG reductions in the building sector exist worldwide. However, multiple barriers make it difficult to realize this potential. These barriers include availability of technology, financing, poverty, higher costs of reliable information, limitations inherent in building designs and appropriate portfolio of policies and programs.
- The magnitude of the above barriers is higher in the developing countries and this makes it more difficult for them to achieve the GHG reduction potential of the building sector.

Commentary on Findings

These findings have been agreed to by all of the countries at the meeting, after a line by line review. It is fair to say there is unanimity among a diverse body with representatives of all major countries of the world. This careful review, supported by a great deal of background work, gives these findings standing in the international community. The full chapter on buildings is 90 pages of detailed text and references. It has been subject to extensive review by experts and governments before the IPCC meeting that concluded on May 4.

There is significance in the findings that may not be apparent. 30 percent of projected CO_2 emissions can be avoided at net economic benefit. This occurs when cost-effective investments are made in energy efficiency. Such investments are beneficial to the consumer, who gains more than she or he pays on an annualized basis, as well as to society.

An important contribution of the AR4 was its thorough review and effort to put on a common footing the different "bottom-up" studies of energy efficiency potential in buildings. By "bottom-up" is meant a characterization of the key technologies that can reduce carbon dioxide emissions, their cost and the quantity of emissions reductions that can be achieved throughout time. The analysis involved a review of 80 studies and a thorough assessment of 17 of these. Such an extensive comparison of the major "bottom up" analyses had never been done before, nor had they been applied to cover the globe. This effort alone has added a great deal of confidence to the analysis of emissions reductions.

It is important to ask how far this energy efficiency will get us in the direction of climate stabilization. To simplify the discussion, I address the question of the degree to which emissions in 2030 might, through energy efficiency alone, be equal to those in 2004. Scenario B2 (one of the two commonly used cases) has ~30 percent higher emissions in 2030 than in 2004 (11.4 Gt/yr vs. 8.6 Gt/yr). Applying all cost-effective mitigation options to buildings would result in constant emissions throughout the period for a B2 baseline scenario. By comparing this result with Figures SPM 7 and 8, this level (if achieved by all other sectors) is consistent with Stabilization Scenarios II and III, 500–550 ppm CO_2 eq. These stabilization levels result in about three degree Centigrade temperature increase.

There are at least three factors that affect these conclusions relating to how much buildings can contribute to mitigation of carbon dioxide:

- The baseline may grow faster or slower than B2 which we have chosen. The baselines studies on which the buildings energy and carbon potential were assessed depended on assumptions in the individual studies we reviewed. Overall, they saw a CO_2 emission growth from 8,6 Gt CO_2/yr in 2004 to 14.3 Gt/yr in 2030. (In the B2 scenario, the growth was to 11.4 GT/yr in 2030. In A1B, the other often cited case, the growth was to 15.6 Gt/yr in 2030.) Using the middle baseline, buildings-related CO_2 would grow to1.4Gt/yr more by 2030 than in 2004 (or 16 percent above 2004 levels) with all cost-effective energy efficiency.
- The supply side can contribute considerably to CO_2 reductions. In the United States, 70 percent of total primary energy used in buildings is electricity. Any

decarbonization of the fuel used to generate electricity translates directly into lower emissions resulting from energy use in buildings. This suggests that over time as more low-carbon supply options become available for electricity generation, energy-related emissions in buildings will decline.

- Notwithstanding these opportunities, a general concern needs to be raised about the fraction of the cost-effective potential that can be realized in this time frame. This will depend a great deal on policies that countries have chosen to implement, and the willingness of citizens to spend time and money on energy efficiency,

This brings us to the issue of policies. The current report reviews performance of a large number of policies in many countries. No single policy is seen to work everywhere. Yet, unlike the previous assessments, there is evidence of considerable success with individual policies in different places. We have reviewed programs aimed at the whole building: building codes; building certification and labeling programs; and education, training, and energy audits. We have reviewed programs aimed at appliances, lighting, and plug loads: standards and labeling; voluntary agreements. We have studied cross-cutting programs, including utility demand-side management programs; elimination of energy subsidies; creation of financial incentives for energy efficiency; public sector leadership and procurement programs; promotion of Energy Service Companies; energy efficiency obligations and tradable energy-efficiency certificates; and Kyoto Protocol's Flexibility Mechanism. All of these—which the exception of the last which does not apply to the United States—has a realm in which it is highly effective in bringing forth energy efficiency. In addition, to be successful in mitigating emissions over time, the report notes the importance of expanding R&D efforts.

Findings from Previous Assessments[1]

The previous assessment (the Third Assessment Report TAR) devoted little attention to sectoral analyses of GHG mitigation. In spite of this cursory assessment, the report did estimate that the buildings sector had the potential to achieve levels of carbon emissions in 2010, 2020, and 2050 that were roughly equal to those in 1998 (Synthesis Report, IPCC TAR, pages 315 and 316). These estimates are similar to those obtained in AR4—somewhat more optimistic depending on the baseline assumption. However, they are based on very little evidence, as much less rigorous literature review was conducted to support the findings. They were largely based on expert judgment.

The Second Assessment Report, on the other hand, devoted a full chapter to mitigation of greenhouse gas emissions from buildings. The chapter provides a description of technologies for energy efficiency in buildings. It is not as complete nor as rich as in the AR4. The chapter describes the key policies and programs that had been attempted to that time. In general, the policies were well described in the report, but there was much less information available about evaluation of policy results. While this area has improved in the AR4, it is still evident that evaluation of policies and programs is not adequate. The SAR does not attempt an evaluation of bottom-up assessments. It reviews several scenarios that project additional energy efficiency as compared with baseline cases, but is not able to pull out of them any direct information about emissions reductions from buildings.

Conclusions

I do not find anything contradictory among the three assessments. In reviewing the SAR, I am struck by how little information on economics or projected savings was in that report. It was primarily focused on describing what was known about energy use in buildings, including data on how energy has been used in the buildings sector. But there was little information that might be seen as policy relevant.

The TAR provided much less information. But the authors were willing to make guesses on the potential for emission reductions at cost-effective levels. These were based on a given baseline and a very small number of studies that were cited in the chapter. Thus, it would not have been possible for policy-makers to place much reliance on the mitigation potentials from the TAR.

AR4 has come the farthest in generating information that can be useful for policy-makers. We can be certain that there are many technologies to reduce emissions. Many of these are described in depth in the report. There is experience with a wide range of policies and programs, some of which have shown considerable success in

[1] I should note that I was a lead author in the TAR and a convening and coordinating lead author in the SAR and AR4. Thus, I am in a good position to observe the evolution of the reviews over a fifteen year period.

individual countries. The report casts a broad net in assessing mitigation potential in the sector and finds consistency among many different studies in different countries.

There remain major shortcomings. The mitigation potential studies are still too limited in technology scope and much effort was needed in putting them on a relatively consistent basis. These studies focus attention on technologies that are available today. They shed little light on the question of the magnitude of energy savings and CO_2 mitigation possible as a function of higher carbon charges. This is because there are so many energy efficiency options available that are presently not being adopted that the authors do not address advanced technology.

There is one other important point to make about the sector. Unlike the supply sector, where carbon charges will be needed to bring about adoption of certain advanced technologies, the buildings sector generally needs targeted policies—including regulatory policies and market based approaches—to achieve mitigation goals. This is because of the large number of barriers that exist in the marketplace that deter investment in energy efficiency.

BIOGRAPHY FOR MARK D. LEVINE

Mark D. Levine, Director Emeritus of the Environmental Energy Technologies Division at Lawrence Berkeley National Laboratory, has returned to full-time leadership of the China Energy Group Leader in March, 2007. While serving as Division Director, 1996–2007, Dr. Levine led the division to a doubling of funding during periods of declining federal funds. The Division has a staff of about 450 researchers and support staff. The research is on energy efficiency technology for buildings, indoor air quality, and other key clean energy technologies (advanced batteries and low NO_X combustion). The Division is an international leader in analysis of key national and energy efficiency policy-related issues.

His major passion in the past two decades has been energy efficiency in China. He again leads the China Energy Group full-time at LBNL since turning over responsibility for the larger Division. The China Energy Group works closely with tens of leading institutions concerned with energy efficiency and hundreds of researchers and policy-makers on the topic in China. It has played a leading role in collaborations leading to appliance efficiency labels and standards, targets for industrial energy efficiency, improved energy scenarios and data, building energy standards, and a host of other activities promoting energy efficiency in China.

Dr. Levine leads prominent national and international non-profits in energy and environment. He is Board Chair (Center for Resource Solutions), Board Member (American Council for an Energy Efficient Economy, Center for Clean Air Policy, Shanghai Pacific Energy Center, and the California Clean Energy Fund), and Member of Advisory Boards (Asian Pacific Energy Research Center in Tokyo and Beijing Energy Efficiency Center). He is a delegate to and Coordinating Lead Author for the Intergovernmental Panel on Climate Change.

He has authored more than 100 technical publications, most relating to energy efficiency and methods of reducing carbon emissions to the atmosphere. Dr. Levine was co-leader of the report "Scenarios for a Clean Energy Future" as well as a coleader of a recent study of energy and carbon futures of China. He was also a Lead Author of sections on mitigation for the 1995 and 2001 report of the Intergovernmental Panel on Climate Change. He has led a major international study for the World Energy Council on energy efficiency.

In 1999, he was elected to be a fellow of the California Council on Science and Technology, California's equivalent to the National Academy of Sciences. He graduated *summa cum laud* from Princeton University and received Fulbright and Woodrow Wilson fellowships. He holds a Ph.D. from UC–Berkeley.

Chairman GORDON. Dr. Pizer.

STATEMENT OF DR. WILLIAM A. PIZER, FELLOW AT RESOURCES FOR THE FUTURE AND SENIOR ECONOMIST AT THE NATIONAL COMMISSION ON ENERGY POLICY

Dr. PIZER. Thank you, Mr. Chairman, for the opportunity to talk about the recent IPCC report.

Let me just start by saying the summaries I am going to give you here today are not necessarily reflecting the opinions of my colleagues at Resources for the Future, which is an organization that does research on environment, energy and natural resource questions but does not take positions on matters of public policy. It also does not necessarily reflect the opinions of all my co-authors. There were more than a dozen authors on my chapter of the IPCC, and the report reflects all those different perspectives, and I will be sharing some of my own personal views as I summarize the report.

If I try to summarize the conclusions of the report about the costs of mitigation on the overall aggregate level, the way I think about it is the following. There are a variety of different stabilization targets we could think about over the next century, ranging from doing absolutely nothing and at the end of the century looking at somewhere between perhaps a three- and seven and one-half-degree Celsius increase in temperatures, or we could do something really aggressive and try to stabilize concentrations at almost current levels and have very rapid reductions in emissions.

Now, obviously, the cost of doing nothing, if we ignore the environmental consequences that were mentioned earlier in terms of costal impacts and ecosystems and health and food and things like that, if we ignore those sorts of impacts, and we do nothing, the cost is going to be nothing.

On the other hand, if we do something aggressive like try to stabilize concentrations rapidly, try to avoid more than two degrees of warming globally, well, the report suggests that the cost could be perhaps as much as three percent of global income in the year 2030. If we think about up to three percent, the report actually doesn't have a lot of data on what the costs of stabilization are at these very low levels. There is a lot more data on things in the middle, and there the estimates range from something like a six-tenths of a percent increase, that is a net gain to the global economy, to somewhere up to about a two and one-half percent cost of income.

If we compare these estimates to the last assessment report as Dr. Levine just did, the main difference is that the new report suggests these very low and possibly negative costs, that is, maybe a six-tenths of a percent gain to the global economy. And the reason for this is that the new report considers models, first of all, which incorporate more of the energy efficiency opportunities that Dr. Levine mentioned, and they also include the possibility that new energy technologies could have very broad economic benefits; things like, you know, the Internet or mobile technologies that really advance overall economic growth.

So if I look at these conclusions and I try to think about observations, there are really four that I would like to make in my opening remarks, and they concern uncertainty, the need for public support for R&D, the need for or the importance of efficient global solutions, and last but not least, trying to put these into maybe a more accessible framework. So let me just quickly go through those.

First of all, uncertainty, an important thing to realize, this range of estimates that I just gave you is not actually, does not have a probability associated with it. The cost could actually be higher or lower, and the reason is is that this is a collection of best guesses. And if you think about, for example, your office basketball pool, you know, most of the people bet on the top seeds. Right? Well, in eight of the last 29 championship games someone other than the top two seeds have won. So what that means to me is when you look at a collection of best estimates, it is a good way to predict the likely outcome, but there is also a reasonable chance there is going to be something else happening. And in terms of thinking about policies to deal with climate change, it is very important to think about what is going to happen if our best pick does not end up being right.

The second observation concerns technology, and I mention that the low-cost estimates that we have seen in the recent report hinge on energy efficiency opportunities, as well as the opportunity for new technologies to lead to broad economic benefits. And one of the potential problems, for example, is that as we invest in these new technologies that have broad economic benefits, we may be taking away from other technologies that also have broad economic benefits. So to me the lesson and the lesson in the report is actually the need for broad public support of research and development, very much like the ARPA–E Policy that has come out of this committee.

The third observation I would make is that all the estimates in this report emphasize the need for broad, flexible global solutions. Hence, to the extent we don't have those solutions, it is going to be more expensive. So to me the lesson for public policy in the United States is to think about broad, flexible, domestic policies and engagement with the rest of the world to try to get similar policies elsewhere.

The last thing I want to mention is that if you want to try to make sense of these cost estimates, things like two percent of global income or something like that, I think a useful thing to do is to try to break it down to what it means for a household. If we think about what household income is likely to be in the year 2030, where a lot of these cost estimates focus, the median household is probably going to be around $55,000 per household, that is, half the households will be more wealthy and half will be poorer.

If you take half a percent of global income and apply it to that household, it would be about $275, and that is kind of the moderate approach to stabilization. If you take the more aggressive approach, it would be something more like $1,650. You could also turn that into prices. The more aggressive approaches, trying to limit warming to two degrees, would be something like a dollar per gallon of gasoline or maybe several cents per kilowatt hour. The more moderate proposals would be something like 20 cents a gallon of gasoline and maybe one cent per kilowatt hour.

So to me if you are going to try to make a decision about what sorts of long-term stabilizations to go for, you have to look at these costs and weigh them against the benefits that we are getting, somewhere in the middle, maybe a two to five degree likelihood of warming, or something more aggressive that would really limit warming to being less two degrees.

So in summary I would just emphasize that the report has a range of estimates, and if we are thinking about policies, we need to think about policies that are going to be responsive to, you know, unlike the outcomes that it is more or less expensive. We need to deal with the fact that technology is very expensive, and we can't just set a cap and trade in motion and go home. We are really going to need public support for R&D. Third, that we need to pursue broad and flexible domestic policies and engage the rest of the world, and last of all, to make some sort of choice about stabilization. We are going to need to come to grips with how much we want to reduce the risk of climate change and how much we are willing to spend.

Thank you.

[The prepared statement of Dr. Pizer follows:]

PREPARED STATEMENT OF WILLIAM A. PIZER

Thank you, Mr. Chairman, for the opportunity to offer testimony before the committee on the Working Group III contribution to the IPCC Fourth Assessment Report: *Climate Change 2007: Mitigation of Climate Change,* on which I served as one of more than 100 lead authors. Over the past decade, I have had the privilege of working on energy and environment issues for organizations as diverse as the President's Council of Economic Advisers and the National Commission on Energy Policy. Currently, I am a senior fellow at Resources for the Future (RFF), a 55-year-old research institution headquartered here in Washington, D.C., that specializes in energy, environmental, and natural resource issues. RFF is both independent and nonpartisan and shares the results of its economic and policy analyses with members of all parties, environmental and business advocates, academics, members of the press, and interested citizens. RFF neither lobbies nor takes positions on specific legislative or regulatory proposals, although individual researchers are encouraged to express their opinions, which may differ from those of other RFF scholars, officers, and directors. I emphasize that the views I present today are mine alone and do not necessarily reflect those of any group with which I am affiliated, including the IPCC.

On May 4, the IPCC released the Fourth Assessment Report (AR4) Working Group III Summary for Policy-makers (SPM). While the underlying report contains literally hundreds of pages surveying estimates of mitigation costs over the past six years, three tables in the SPM summarize this information, reproduced below. Those tables are then further summarized in the text of bullet points #5 and #6:

- Both bottom-up and top-down studies indicate that there is substantial economic potential for the mitigation of global GHG emissions over the coming decades, that could offset the projected growth of global emissions or reduce emissions below current levels.
- In 2030 macro-economic costs for multi-gas mitigation, consistent with emissions trajectories towards stabilization between 445 and 710 ppm CO_2-eq, are estimated at between a three percent decrease of GDP and a small increase, compared to the baseline. However, regional costs may differ significantly from global averages.

It goes without saying that condensing information so dramatically can leave the end product open to misinterpretation. The further question of what a statement like "a three percent decrease of GDP" really means can create additional confusion. With that in mind, I would like to start by taking some time to interpret the three tables in the SPM. Then I would like to make three additional points that are not emphasized in the summary bullet points but are discussed elsewhere in the SPM and underlying chapters.

First, the range of estimates should not be interpreted as being a "likely" range—for the most part, it generally reflects a range of "best estimates" produced in the literature. Second, there are a couple of reasons why we might want to be cautious about the low end of the cost estimates. And third, all these estimates assume an efficient global climate policy; to the extent that actual policies deviate from this benchmark—which remains useful and quite standard—it is almost certain that costs will be higher.

I would like to conclude by making a few remarks about how we might use all of this information to think about our near-term policy choices in the United States.

What does the SPM say about costs?

There are a variety of ways to think about the cost of reducing greenhouse gas emissions. One is to think about how much we have to pay for each ton being reduced. Another is to think about the impact of making those payments on other things we care about—like our income, consumption, or well-being. Alternatively, we might ask about effects on employment or energy prices, or about the distribution of these various impacts on different regions, sectors, or demographic groups.

Most studies of mitigation costs focus on the first two measures—payment for tons reduced and the impact on income—and do so with relatively little disaggregation. For that reason, the IPCC similarly focuses on these two measures in the SPM and the underlying report.

Table SPM 1: Global economic mitigation potential in 2030 estimated from bottom-up studies.

Carbon price (US\$/tCO_2-eq)	Economic mitigation potential ($GtCO_2$-eq/yr)	Reduction relative to SRES A1 B (68 $GtCO_2$- eq/yr) %	Reduction relative to SRES B2 (49 $GtCO_2$- eq/yr) %
0	5-7	7-10	10-14
20	9-17	14-25	19-35
50	13-26	20-38	27-52
100	16-31	23-46	32-63

Table SPM.2: Global economic potential in 2030 estimated from top-down studies.

Carbon price (US\$/tCO_2-eq)	Economic potential ($GtCO_2$-eq/yr)	Reduction relative to SRES A1 B (68 $GtCO_2$ eq/yr) %	Reduction relative to SRES B2 (49 $GtCO_2$ eq/yr) %
20	9-18	13-27	18-37
50	14-23	21-34	29-47
100	17-26	25-38	35-53

Source: AR4, Working Group III, SPM

The two tables above, reproduced from the SPM, summarize and synthesize work completed over the last six years examining how much we would have to pay, per ton, for different volumes of reductions. The rows categorize opportunities based on maximum estimated cost. As we move down the table to higher maximum estimated costs, we see more opportunities, as they necessarily include preceding, cheaper opportunities. The columns then report the volume of reductions available at or below the per-ton cost indicated in each row, first in actual tons (column 2) and then in relation to two different estimates of what emissions might otherwise be in 2030 (columns 3 and 4). All estimates reflect calculations for 2030.

Reading the bottom row of Table SPM 2, for example, we find that the literature published over the last six years indicates between 17 and 26 billion tons of carbon dioxide—or the carbon dioxide equivalent of other greenhouse gases—is available at or below \$100 per ton.

This kind of data—schedules of emissions reductions and price—are useful for several reasons. First, these prices on carbon dioxide can be converted relatively easily into prices on things like electricity and gasoline. One dollar per ton of carbon dioxide is roughly one penny per gallon of gasoline, one-tenth of a cent per kilowatt-hour for coal-fired electricity, and one-twentieth of a cent per kilowatt-hour for gas-fired electricity. Thus, \$20 per ton of carbon dioxide would be an increase of about 20 cents per gallon of gasoline, two cents per kilowatt-hour for coal-fired electricity, and one cent per kilowatt-hour for gas-fired electricity. Second, this data can be used to gauge how much harder it is to squeeze out more and more reductions. Note that going from \$20 to \$50—a 150 percent increase in price—brings out about 50 percent more reductions. Yet, doubling again to \$100 brings out only another 20 percent. Emissions reductions get harder the more you do. Finally, they can be used to make crude calculations of overall costs, calculations that later can be checked against estimates from more sophisticated models. The calculation is usually made as one-half the price times the volume of reductions, where the "one-half" accounts for the fact that these are maximum prices; many of the reductions would cost less. Applying that to the bottom row of Table SPM 2, for example, we could estimate the cost of 26 billion tons of reductions at 1/2 x \$100 / ton x 26 billion tons = \$1.3 trillion.

While this simple approach is a good starting point for thinking about costs, one advantage of a top-down model is its ability to internally and consistently add up costs, to consider the interaction of mitigation policies with other fiscal policies, trade, and possible market failures, and to consider how costs are spread out over time. Top-down models can also model emissions pathways that stabilize greenhouse gas concentrations in the atmosphere. With that in mind, we turn to Table SPM 4.

Table SPM.4: Estimated global macro-economic costs in 2030[18] for least-cost trajectories towards different long-term stabilization levels.[17, 18]

Stabilization levels (ppm CO_2-eq)	Median GDP reduction[19] (%)	Range of GDP reduction [19, 20] (%)	Reduction of average annual GDP growth rates (percentage points) [19, 21]
590-710	0.2	-0.6 – 1.2	< 0.06
535-590	0.6	0.2 – 2.5	<0.1
445-535[22]	Not available	< 3	< 0.12

Source: AR4, Working Group III, SPM

This table shows, along different rows, the estimated cost of stabilization at three different ranges of concentrations of carbon dioxide and other gases, expressed in carbon dioxide equivalent. These ranges are given in the first column. Costs in the second and third column are expressed as a share of global GDP, which is a measure of the income flowing to the world's inhabitants in the form of wages, capital income, and the sale of natural resources. That is, it is the fraction of income that is no longer available for consumption or investment by individuals, firms, or governments, because it is being used to reduce greenhouse gas emissions.

The fourth column indicates the corresponding effect on growth, a measure that I personally find confusing. Any effect on income, when viewed far enough into the future, or from far enough in the past, will be a small fraction of annual growth. To put this into perspective, a policy decision conducted in 1983 concerning a $120 billion cost today—one percent of U.S. GDP—could have been expressed as a 0.05 percent reduction in annual growth (much like the first row of Table SPM 4). Had we viewed the decision in 1960, however, the effect would be half, a 0.025 percent reduction in growth. Regardless, the cost is $120 billion or one percent of GDP today, which is why I tend to focus on columns two and three.

The range of estimated costs summarized in columns two and three is defined by the range of top-down modeling estimates published over the last six years, excluding the highest and lowest 10 percent of the estimates. In the case of the lowest range, 445–535 ppm carbon dioxide equivalent, there are too few studies to say anything more than that the estimated costs in all the available studies are below three percent of GDP.

Three percent of GDP means a three percent loss of income; whether that—or some other number—is a lot or a little depends on how we view mitigation benefits and other consequences.

Today, three percent of GDP in the United States would mean $360 billion. (For the world, it would be about five times higher.) These costs are annual, so that would be $360 billion per year. In terms of households, we could consider the effect on the median household—that is, the household for which half the population is wealthier and half the population is poorer. According to the Census Bureau, median income in 2005 was about $46,000. Three percent would then mean a cost of about $1,380, per year, for the median household. Of course, household income will be a lot higher in 2030, right? Yes and no. Mean household income has grown at almost 1.3 percent per year for the past 40 years. However, *median* household income has only grown at 0.7 percent. Projecting forward at the historic rate suggests median income would be about $55,000 and three percent would amount to $1,650.

More importantly, whether we believe $1,650 is a lot or a little—or whether we believe a different number is a lot or a little—to a large extent hinges on what we think it is worth to mitigate the predicted effects of climate change and by how much. We return to this issue at the end of my testimony. First, we need to go back to the numbers and make a few important points.

The range of estimates does not have a likelihood or probability associated with it.

A somewhat misleading feature of providing a range of estimates, as we see in Tables SPM 1, 2 and 4, is that it suggests the true outcome will likely fall in that range, and the question is simply where. This is particularly true in Table SPM 4, where the range is explicitly referred to as representing a "10th and 90th percentile range of the analyzed data." A probabilistic interpretation, however, is not right. The range of estimates, particularly in Tables SPM 2 and 4, reflects the range of best estimates provided by different experts in the literature. In some cases, the same model is included with different assumptions, but generally each estimate represents the researchers' best attempt to estimate future emissions and mitigation costs. As such, there is relatively little effort to quantify uncertainty in the estimate.

As an analogy, suppose you asked a group of experts to estimate the number of "heads" in 100 coin flips. Most likely, they would all say 50, which is the most likely outcome, and the "range" of estimates would be exactly 50. However, it is a straightforward statistical exercise to show that there is a one in four chance that the number of heads will exceed 55 or be less than 45. And there is a one in 20 chance that it will be at least 60 or no more than 40. The range of expert estimates says little about the actual spread of outcomes. In other words, there is a difference between a range of best guesses and a range that represents some notion of likely outcomes. While there are well-established procedures for expert elicitation that generate ranges with probabilistic interpretations, those procedures have not been applied to this question of mitigation costs.

There are reasons to be cautious about the low end of the cost estimates

A question that might have arisen in the context of Tables SPM 1 and 2 is why two separate tables contain what is apparently the same information. Table SPM 1 makes use of a particular kind of study, referred to as "bottom up." Researchers itemize different actions or technologies that could be applied to reduce emissions. They estimate the cost per ton of that action or technology, as well as the volume of reductions that could be reduced. Adding up the volume of reductions available at or below different price points yields these bottom-up estimates.

Table SPM 2 summarizes results from an entirely different kind of study, referred to as "top down." In these studies, researchers have constructed complete, though necessarily approximate, models of the global economy that include emissions of greenhouse gases. These models are designed to replicate the (historically) observed responsiveness of consumers and businesses to changing prices—including energy and other activities causing greenhouse gas emissions. These models can be used to simulate what will happen if the price of greenhouse gases is increased and, in particular, how emissions of greenhouse gases will be reduced.

Both kinds of approaches have strengths and weaknesses. Bottom-up approaches can include a wider variety of specific technological options that are often too numerous and detailed to be incorporated in a top-down model. Top-down models, meanwhile, better represent historical patterns of behavior and responsiveness. They also enforce accounting consistency—all the flows of goods and services are tracked and supply must equal demand in every market. Bottom-up analyses are often tabulations of opportunities that run into difficulties when some opportunities, like energy efficiency, interact with others, like fuel switching, to create the risk of double counting. Bottom-up analyses are also not forced to use the same baselines; indeed, the different sectoral analyses compiled in Table SPM 1 used different baselines, as detailed in the notes to Figure SPM 6.

But the most significant concern about bottom-up analyses, acknowledged in the definition of "economic potential" given in Box SPM 2, is that they assume the removal of barriers that often prevent or increase the costs of actions being represented. This is especially true for the "zero-cost" opportunities, often energy efficiency projects, highlighted in Table SPM 1. For example, it is often hard to capitalize energy efficiency investments in buildings, making such investments less profitable for investors who might sell the building. Similarly, increased fuel economy in automobiles may pay for itself—but those same technologies can often be used to increase power and size, keeping fuel economy unchanged. If consumers put a higher value on these other characteristics, the proper way to value the cost of higher fuel economy is not the actual cost of the technology, but the forgone value to consumers of not having these other characteristics. Regardless of what barrier is preventing a zero-cost option from being adopted, it is sensible to imagine that it will not be entirely costless to remove it. Similar concerns arise for the positive cost opportunities, where the presence of barriers similarly tends to raise costs above the bottom-up estimates. Whether this concern is an argument for supplemental policies to remove barriers, for higher cost estimates, or for both, is unclear. It is worth noting that Chapter 11 qualified the bottom-up estimates as having "medium agreement and medium evidence."

Meanwhile, none of this is to say that *no* zero- or low-cost opportunities exist; rather, it leads me to put less confidence in the lower end of the bottom-up range of estimates. It also raises the question of exactly what kinds of policies are going to be required to remove barriers and to get at these opportunities. Market-based policies that put a price on carbon dioxide emissions are clearly not enough, as the zero-price opportunities reflect, suggesting the need for direct regulation or other interventions.

It should be noted that almost by construction, top-down models ignore the possibility of zero-cost mitigation opportunities—as reflected by the absence of a "$0" line in the Table SPM 2. While viewed as a strength by economists like myself, those who have greater confidence in the zero-cost opportunities and the possibility of policies to achieve them, see this as a weakness.

Given these observations about differences between top-down and bottom-up models, it is remarkable that the range of estimates is quite similar across the estimates, as presented in Tables SPM 1 and 2. In the previous, Third Assessment Report (TAR), the top-down estimates tended to show higher costs and lower mitigation potential. Chapter 11 attributes this to two changes in top-down models since the TAR: inclusion of other greenhouse gases and endogenous technological change, both of which would be expected to lower costs. Let's look briefly at how AR4 top-down estimates compare to the TAR.

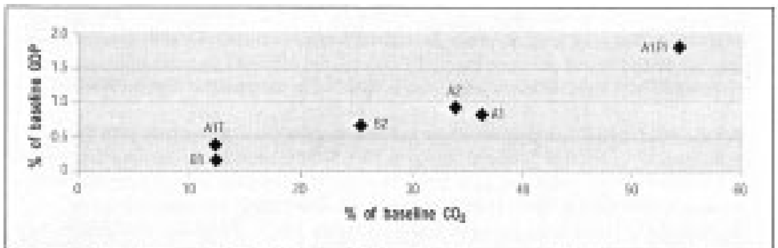


Figure 8.19: Average GDP and CO_2 reductions in 550 ppmv stabilization scenarios; year 2050 (labels identify different scenario groups).

Source: TAR, Working Group III, Chapter 8

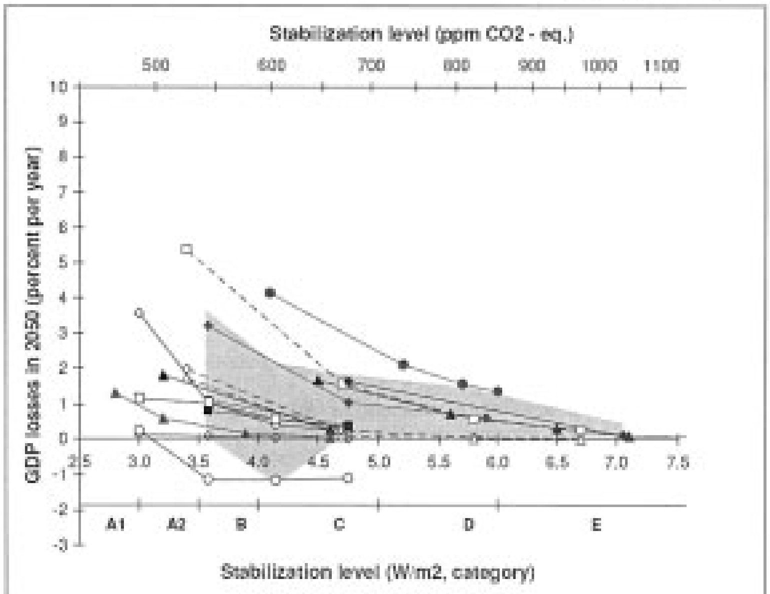


Figure 3.25(a), 2050: Relationship between the cost of mitigation and long-term stabilization targets (radiative forcing compared to pre-industrialization level, W/m^2 and CO_2-eq concentration).
Note: Individual lines show selected studies; grey shaded region represents the 80[th] percentile of scenarios.

Source: AR4, Working Group III, Chapter 3

Compared to the TAR, the new AR4 presents a range of estimates with a similar upper bound, but with a new lower bound including possible economic gains.

Only two pages (section 8.4.3) in the TAR focus on the cost of stabilization comparable to the new AR4 review. Figure 8.19, reproduced from that section above, shows an average of results from six models for stabilization at 550 ppm carbon dioxide (that is, excluding other gases) and using different baselines. The figure provides a snapshot of reductions and costs in 2050. The horizontal axis indicates the different volume of reductions required to meet the 550 concentration target, based on the different baseline emissions scenarios. The vertical axis shows costs as a percent of global GDP. The figure suggests costs of between one-tenth of one percent and almost two percent of global GDP, depending on the baseline.

For comparison, we can examine Figure 3.25(a) in the Fourth Assessment Report. Unlike the TAR, this figure shows some models independently while the full range of results, excluding the top and bottom 10 percent, is shaded grey. Here, there is no attempt to draw out the effect of different baseline emissions assumptions, as in the previous figure; instead we see the GDP effects along the vertical axis for different levels of eventual stabilization along the horizontal axis. For comparison with the TAR review, we focus on the "category C" levels, or about 650 carbon dioxide equivalent (i.e., including the other gases that were excluded in the TAR). What we see is that the upper end of the range is still around two percent, but now the lower end includes a *net gain* of one percent.

What explains this difference? As noted previously, two reasons are given in the text. One is that the new scenarios include studies with multiple greenhouse gases, which generally lowers costs because they offer cheaper mitigation opportunities in percentage terms. While true, it does not explain negative costs—in top-down models, as also noted earlier, negative cost options typically do not exist, even for other greenhouse gases. Instead, negative costs can arise in models where technological change is endogenous, a point we now examine in more detail.

Assumptions about technological change can lower costs and even make them negative-but we should be cautious.

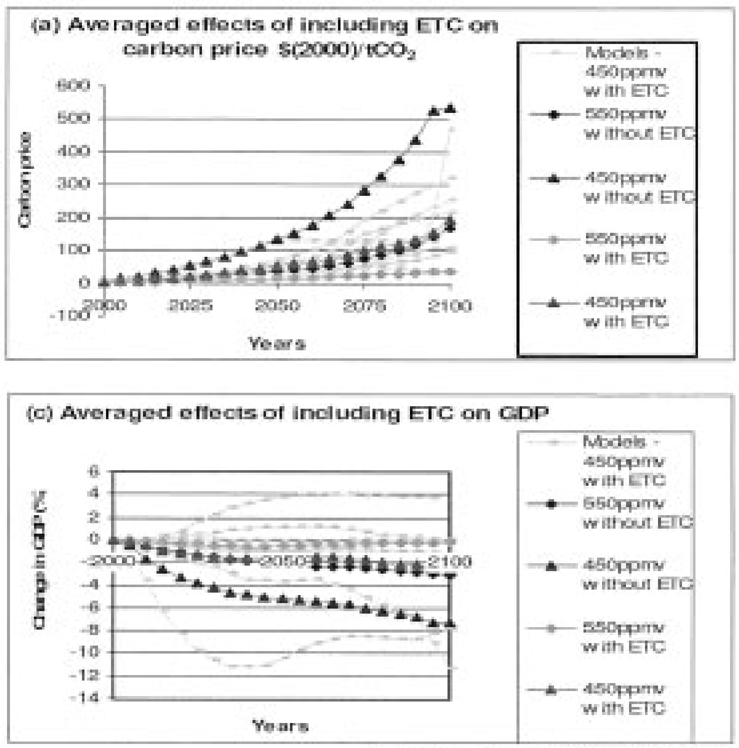
Assumptions about technology have always been viewed as critical to the estimate of mitigation costs—this was a key observation in the TAR. A new development since the TAR is use of endogenous technological change (ETC) in some models. What is endogenous technological change? Most models used to estimate the cost of mitigation take the process of technological change as given; that is, the availability of new technologies at particular times and at particular costs is one of the assumptions that researchers plug into their model. An alternative is to have the model figure out when these technologies become available and at what cost, typically in response to spending on research and increased demand. At first blush, this makes all the sense in the world: of course, technologies and costs should be responsive to policies and behavior. The problem, of course, lies in the details.

More specifically, the problem is that there is relatively little empirical evidence about how technological change will respond to increased spending or increased demand for emissions reductions. On the one hand, there is evidence in the literature on spill-over effects that increased spending on emissions-reducing research will yield net economic gains because the return to research spending is extremely high. On the other hand, there is evidence in the literature on crowding out effects that increased spending emissions-reducing research will come at the expense of other high-return research, such as health care. How these two competing effects play out determines the extent to which ETC reduces costs or even produces negative costs.

In yet another modeling arena, we often see the costs of various technologies decline almost naturally with increased use and production—for example, the spectacular decline in the cost of computing power over the past three decades. It is easy to imagine implying such a relation to the costs of new emission-reducing technologies as experience accumulates. Yet, it is hard to isolate what causes that decline—namely production and use alone, or possibly unmeasured and coincident spending on research—and to know whether similar declines will occur for other technologies.

Despite these unresolved empirical questions, researchers have produced a large volume of work over the past six years in which they have experimented with making the availability and cost of new, emissions-reducing technologies responsive to additional research and demand. The two figures below, taken from Figure 11.9 in the underlying Working Group III report, summarize a major synthesis study looking at the consequences of this "endogenizing" of technological change—that is, making it responsive to additional research and demand. These figures summarize a collection of results from different models, with the dark colored lines showing averages across different for each of four scenarios and the light grey lines showing the spread across different models for one scenario. The first figure, Figure 11.9(a) shows carbon prices, analogous to those reported in Tables SPM 1 and 2, associated with two different levels of stabilization, 550 and 450 ppm carbon dioxide, both with and without endogenous technological change. The second, Figure 11.9(c) shows the effect on global GDP, similar to Table SPM 4.

The figures are complex, but highlight two important points. The first is seen by comparing the brown triangles ("450 ppmv without ETC") to the red triangles ("450 ppmv with ETC"). The "with" and "without" ETC refers to whether technology is allowed to adjust in response to a constraint on carbon dioxide emissions. The obvious point is that it makes a huge difference, more than halving the costs in 2030, whether viewed as the price of carbon dioxide or the loss of GDP. The second point is that there are widely divergent results across models—the light grey lines show the individual model results for the “450 ppmv with ETC” case. Some models show gains, other show losses; even excluding the extremes, the range is from a one percent gain in GDP to a three percent loss in 2030.



Source: AR4, Working Group III, Chapter 11

My view is that while the estimates holding technology availability and cost fixed are clearly wrong, we do not have a sufficient understanding of the empirical relationship between research spending, demand for emissions-reducing technology, and eventual decreases in technology cost to give equal weight to the cost estimates produced by models where technology is endogenous. Both the significantly different estimates across models and the large effect on the central values of switching endogenous technological change on and off make this a very important point. It is precisely these models with endogenous technological change that drive the lower end of the range of estimates in Tables SPM 2 and 4. Therefore, I tend to be cautious about the plausibility of these lower-end estimates, especially so for the estimates suggesting negative costs in Table SPM 4.

The assumption of global least-cost strategies means costs are likely to be higher.

My last point about the SPM cost estimates, highlighted in Box SPM 3, is that the estimates in these tables generally assume a global, least-cost strategy. That means all nations are engaged in market-based policies that put a single price on emissions reductions in all sectors throughout the world. Deviation from that—for example, the lack of participation (or least cost participation) of key developing countries or use of less efficient sectoral policies—will raise costs, according to some estimates, by a factor of two or more.

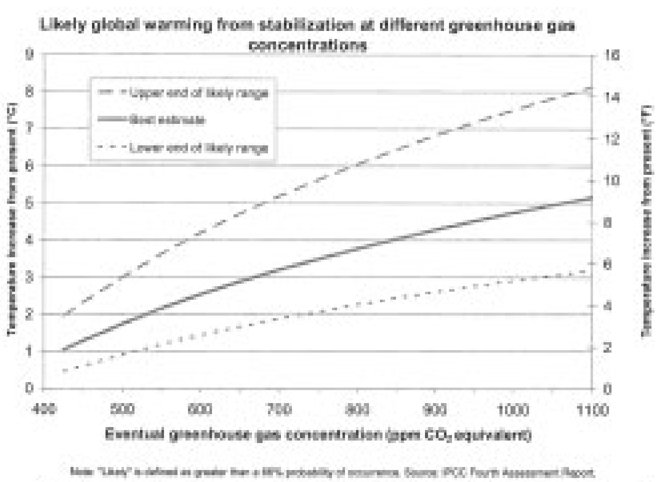
None of this means "do nothing;" it simply means we need a thoughtful consideration of costs and benefits.

In summary, Table SPM 4 provides perhaps the simplest relationship between various long-term environmental goals and the economic impact, in terms of forgone income, estimated to result in 2030. According to that table, stabilization in the 650 ppmv carbon dioxide equivalent range will cost between -0.6 and 1.2 percent of global income, in the range of 550 ppmv between 0.2 and 2.5 percent, and in the range of 450 ppmv less than three percent. Alternatively, we could use Tables SPM 1 and 2 to assess the mitigation possibilities at different carbon dioxide prices. My three observations on these results are that (1) given my indicated concerns about the low-end estimates in the SPM, my own view about mitigation costs lies at the middle to higher end of the estimated ranges, (2) our uncertainty about costs is not represented by the given range, which is a collection of best estimates, and (3) actual policy implementations are likely to be more expensive than the indicated range because the global, least-cost benchmark is at best an ideal.

Given my view of these cost estimates—that our best guess is somewhere from a few tenths of a percent of GDP up to three percent, depending on the stabilization target—how do we choose a course of action, especially in the near-term? Here I would offer five possible suggestions.

First, consider what these concentration targets will do to the environment. A colleague of mine, Richard Newell, put together the figure below relating concentration targets to the likelihood of different changes in temperature. Across the horizontal axis are various concentration goals; the vertical axis shows the range of likely temperature increases. Combined with the Figure SPM 1 from Working Group II, reproduced at the end of this document that shows the impacts associated with different levels of warming, we could make decisions about how much we are willing to pay, in terms reduced GDP based on Table SPM 4, to reduce the risk of various outcomes.

Second, consider what cost-benefit analysis suggests. Recent work by William Nordhaus has suggested that near-term benefits of reducing carbon dioxide emissions are about $7 per ton of carbon dioxide. These estimates are very sensitive to assumptions about future interest rates and/or how to value consequences over long periods of time. My own work with colleague Richard Newell on uncertainty and discounting suggests roughly doubling his estimates to about $15 per ton of carbon dioxide.



Source: U.S. Climate Mitigation in the Context of Global Stabilization, RFF Backgrounder

Third, consider practical near-term constraints. Earlier, I mentioned the effect of carbon dioxide prices on gasoline and electricity prices. One limit to efficient market-based approaches that put a price on carbon dioxide is consumers' willingness to pay higher energy costs. If $15 per ton of carbon dioxide implies 15 cents per gallon and something slightly less than 1 cent per kilowatt-hour, that is useful information for calibrating a domestic policy. Another useful benchmark is the effect on coal use. For a variety of reasons—energy security, regional economic interests, pressure on natural gas prices—the effect on coal use is a useful metric. According to the Energy Information Administration, a price of $15 per ton of carbon dioxide in 2020 implies relatively constant coal use compared to current levels.

Fourth, look at what other countries are doing. The price in the EU Emissions Trading Scheme, the only significant carbon dioxide emissions trading program in the world, has fluctuated between $12 and $35 per ton and is currently around $25. These prices give some estimate of what is possible without appreciable dislocation.

Finally, recognize that the most significant lesson in this exercise is the role of technology and technological change. Addressing climate change is not just about picking an emissions target or a price—unquestionably an important part. It is also about designing a suite of policies that support technology development and deployment over time.

I thank you again for the opportunity to appear before this committee, and I would be pleased to answer any questions.

Source: AR4, Working Group II, SPM

BIOGRAPHY FOR WILLIAM A. PIZER

Billy Pizer is a Senior Fellow at Resources for the Future where his research looks at how the design of environmental policy affects costs and environmental effectiveness, often related to global climate change. His research has examined the aggregate level and distribution of regulatory costs, the effect of uncertainty on policy outcomes, the choice among various market-based policies, the role of voluntary programs, impacts on competitiveness, the importance of technological change, and the valuation of environmental benefits over long time horizons.

Pizer was a Lead Author on the Intergovernmental Panel on Climate Change 4th Assessment Report, chaired the DOE review of its Integrated Assessment Research Program, and serves on both the EPA Environmental Economics Advisory Committee and the DOE Climate Change Science Program Product Development Advisory Committee. Since August 2002, Pizer has worked part-time as a Senior Economist at the National Commission on Energy Policy. During 2001–2002, he served as a Senior Economist at the President's Council of Economic Advisers where he worked on environment and climate change issues. He was a Visiting Scholar at Stanford University's Center for Environmental Science and Policy during 2000–2001, and taught part-time at Johns Hopkins University during 1997–1999. His work has been published in the *Review of Economics and Statistics, Journal of Public Economics, Journal of Environmental Economics and Management,* as well as other scholarly journals and books. In 2006 he won, with Richard Newell, the Petry Prize for their work on discounting.

STATEMENT OF MR. STEVEN E. PLOTKIN, TRANSPORTATION ENERGY ANALYST WITH THE CENTER OF TRANSPORTATION RESEARCH AT THE ARGONNE NATIONAL LABORATORY

Mr. PLOTKIN. Mr. Chairman and Members of the Committee, thank you for this opportunity to discuss the IPCC's finding on mitigating greenhouse gas emissions from the transport sector.

Transport is especially important because it represents nearly a quarter of energy-related greenhouse emissions, because is it growing rapidly, and because it is bound so tightly with oil. Oil supplies 95 percent of its fuel, and transport represents half of world oil use and about two-thirds of U.S. oil use.

On their currently path world transport emissions and oil use will grow at about two percent per year. That means that by 2030, they will have grown by 80 percent, almost doubling. Although much of that growth will occur in the developing world led by China, U.S. transport emissions and oil use are also expected to grow at nearly two percent per year.

If conventional oil production cannot keep pace with this rapid growth, the most likely supplemental fuels would be liquid fuels from tar sands, heavy oil, coal, and natural gas. These supplements would tend to increase greenhouse emissions.

Further, a transition to these fuels would probably not go smoothly and supply disruptions and very high prices would be likely. This creates a strong added incentive to take steps to reduce the growth rate of transport's oil use.

Much of the growth in transport emissions is driven by the rapid increase in ownership of personal vehicles, including two-wheel vehicles in the developing world. Although much attention is focused on this growth, both freight transport and air transport deserve close attention also. Freight now counts for over one-third of transport energy use and greenhouse emissions and actually is growing more rapidly than passenger transport. And air travel accounts for 12 percent of emissions. It has got a five percent growth rate, which is the fastest of all modes, and its effects on climate change are magnified by airplane contrails and the cirrus cloud enhancement caused by the high altitude of aircraft emissions.

Since the IPCC's third assessment report in 2001, there have been significant advances in efficiency technology. Direct injection diesel engines, 30 percent more efficient than gasoline engines, have over 50 percent of new car sales in Europe. These engines are much cleaner than older diesels, and their emissions performance continues to improve.

Automakers also have made great strides in improving the performance and reducing the costs of hybrid electric vehicles, and their use is spreading. Their ultimate role, however, will depend on how successful automakers are at further reducing their costs.

Finally, there has been steady progress in hydrogen fuel cell development. But further progress in reducing costs, and increasing onboard hydrogen storage capability, and strong Government support is crucial to future commercialization.

Several potential improvements to new light-duty passenger vehicles, that is cars and light trucks, conceivably double their fuel economy by 2030. These are briefly described in my written testimony, and let me give you an idea of the costs. We are talking about costs that are comparable to leather seats and a sunroof or four-wheel drive. A few thousand dollars. The key issue is whether these technologies will be used for reducing fuel consumption or instead to increase performance and size. EPA estimates that increased weight and acceleration capability has cost the U.S. new car and light truck fleets' fuel economy over five miles per gallon between 1987, and 2005. That is, we can use this technology for fuel economy, or we can use this technology for other things. And although the U.S. may be an extreme case, this type of tradeoff of performance and size versus fuel economy is being made throughout the world.

Technologies exist to reduce greenhouse gasses in other transport areas as well. For example, a combination of aerodynamic and engine improvements could increase the fuel economy of intercity freight trucks by as much as 50 percent when they are on the highway. And biofuels can play a substantial role in reducing greenhouse gas emissions from all transport modes. Displacing as much as a quarter of oil-based fuels by 2050, but only if we make substantial progress in developing the technology for using materials such as switchgrass and wood waste.

There is an array of potential policy tools to help reduce transport greenhouse emissions. In the areas with rapid urbanization and transport systems in the early stages of development, good urban design, development of efficient public transport systems, and promotion of walking and biking can reduce the number and use of personal vehicles while providing excellent mobility and access to services. These policies also have an important role to play in the United States and elsewhere in the industrial world, although obviously much of the die is cast in terms of our dependence on personal vehicles and in the form of our urban areas.

Another key policy tool is from, to reduce greenhouse gas emissions from personal vehicles is the fuel economy standard. Standards are now being widely used, even in countries with much higher fuel prices and vehicle taxes than ours. They have been effective in the past in the United States and elsewhere in slowing the growth of oil use and greenhouse emissions. Some form of fuel economy or CO_2 standard or agreement is now in place in Japan, the European Union, China, Australia, and elsewhere. And the State of California and a group of other states are attempting to establish their own CO_2 standards.

Taxation policies on fuels and vehicles can also play an important role. Some of these policies may translate into a fairly high gasoline tax, however, we can recycle those taxes, we can reduce taxes elsewhere in the economy. If we do that intelligently, the effect on the economy does not have to be negative. Many countries do have a lead tax motor fuels and have lower rates of fuel consumption than countries like ours with low taxes.

However, vehicle travel demand, the demand for vehicles and fuel use are not highly price elastic, so relatively high taxes are required to have major effects on fuel use and greenhouse gas emissions.

For the longer-term there are a number of technologies that can make a major difference in transport emissions but all require significant advances that must be addressed by strong research and development programs. And here governments can play a significant role. Some promising examples are radical improvements in conventional gasoline engines, light-weight materials for vehicles, advanced biofuels from cellulosic materials, hydrogen fuel cell vehicles, plug-in hybrids, blended wind aircraft bodies, and unducted turbo fan engines, and advanced diesel engines for freight trucks.

Mr. Chairman, this concludes my testimony, and I will be delighted to answer any questions.

[The prepared statement of Mr. Plotkin follows:]

PREPARED STATEMENT OF STEVEN E. PLOTKIN

FINDINGS OF THE TRANSPORTATION SECTOR ANALYSIS

Mr. Chairman and Members of the Committee, thank you for this opportunity to discuss the findings of the Intergovernmental Panel on Climate Change (IPCC) on mitigating greenhouse gas (GHG) emissions from the transport sector. I draw extensively in this testimony from Chapter 5 of the full report, of which I was a co-author.

SUMMARY

The transport sector is an especially important focus of policy concern because it represents nearly a quarter of energy-related greenhouse gas (GHG) emissions and is growing rapidly, and because it is bound so tightly with oil—oil supplies 95 percent of its fuel, and transport represents half of world oil use (and about two-thirds of U.S. oil use).

Technologies are available today to sharply reduce the growth of oil use and GHG emissions from transport, but strong government actions will be needed for these technologies to reach their full potential. Useful policies include fuel economy standards, registration and annual fees on vehicles tied to efficiency, public support for transit and urban planning, and a host of others.

For the longer-term, there are a number of technologies that could make a major difference in transport emissions, but all of these require significant advances that must be addressed by strong research and development programs. Some promising examples are radical improvements in conventional gasoline engines; lightweight materials for vehicle structures; advanced biofuels from cellulosic materials; hydrogen fuel cell vehicles; plug-in hybrids; blended-wing aircraft bodies and unducted turbofan engines; and advanced diesel engines for freight trucks.

A combination of careful urban planning and promotion of efficient public transport and walking and cycling can have a profound longer-term positive impact on GHG emissions from urban transport as well as on the livability of cities. Although the greatest impacts will be in the developing world whose cities and transport systems are undergoing rapid transformation, important positive impacts can occur in the industrialized nations as well.

DETAILED TESTIMONY

Transportation accounts for about 23 percent of the world's energy-related GHG emissions, and is the fastest growing end-use sector. Three quarters of its emissions come from road vehicles. If transport energy use and GHG emissions continue on their current path, world transport emissions will grow at about two percent per year; by 2030 they will have grown by 80 percent. Much of that growth will occur in the developing world—the nations outside of the OECD account for 36 percent of emissions today, but are expected to account for 46 percent by 2030, with nations like China leading the way with its astonishing 20 percent/year growth in private vehicle ownership. However, the United States is expected to have transport growth not much lower than the world average during this period.

Much of the growth of transport is driven by rapid increases in the ownership of personal vehicles—including two-wheeled scooters and motorcycles as well as passenger cars. As personal wealth has grown in developing nations, the motorized personal vehicle is being seen as a status symbol as well as a means to faster, more flexible and convenient, and more comfortable travel than public transport. In this part of the world, development of excellent public transport systems and intelligent shaping of urban growth will be crucial to future GHG emissions as well as to adequate access of urban populations to jobs, recreation, and other services.

Although most attention in transportation has been paid to personal travel, freight transport now accounts for over a third of transport energy use and GHG emissions, and is growing more rapidly than passenger transport. Freight operations are driven more strongly than personal travel by energy costs, but pressure to increase speed and reliability and provide smaller "just-in-time" shipments means that there has been an ongoing movement to faster and more energy-intensive modes.

Air travel, most of it for personal travel, is also a crucial sector—currently it accounts for about 12 percent of transport GHG emissions, it is growing the fastest of all modes (five percent/year), and its effects on climate change are magnified by contrails and on cirrus cloud enhancement caused by the high altitude of aircraft emissions.

The importance of the transport sector's energy use and GHG emissions is magnified by the fact that transportation and oil are inextricably linked. . .worldwide, oil supplies about 95 percent of transport energy, and the ratio is similar in the United States—and transport accounts for about 50 percent of worldwide oil use, a share that will grow over time (for the U.S., transport's share is about two thirds). There is now a debate about the likelihood that conventional oil production may be nearing its peak, which could have drastic consequences for both energy security and GHG emissions. If conventional oil production cannot keep pace with transport demand growth, the most likely fuels to supplement oil-based fuels would be liquid fuels from unconventional fossil resources—tar sands, heavy oil, and coal—and liquids synthesized from natural gas. These supplements would tend to increase GHG emissions. In my personal view, it is quite likely that the transition to such fuels would not go smoothly, and supply disruptions and very high prices would be probable. Further, even if oil resource optimists prove to be correct, expanding production to match demand will require huge investments in oil-producing regions with troubled investment environments. If these investments are not forthcoming, future supply problems will be severe. These issues create a strong added incentive to focus on reducing the growth rate of demand for oil.

Efficiency Technology

Improvement in energy efficiency is a key method of reducing GHG emissions. Since the Third Assessment Report (TAR) in 2001, there have been significant advances in efficiency technology. For example:

- Turbocharged direct injection diesel engines, capable of improving fuel efficiency by 30 percent or more over similar gasoline engines, have attained a market share of over 50 percent of new car sales in Europe. These engines are much cleaner than the last generation of diesels, and their emissions performance continues to improve.
- Hybrid-electric vehicles had just been introduced at the TAR's publication; since the TAR, automakers have made great strides in improving their performance and reducing their costs, and their use has spread to bus fleets and recently to urban trucks. They clearly will play a larger role in the future, but the extent of their penetration into the road vehicle fleet depends strongly on further reducing their costs.
- There has been steady progress in hydrogen fuel cell development, especially in reducing the cost, size and weight of fuel cell systems; however, further progress in reducing costs and increasing on-board hydrogen storage capability is crucial to future commercialization—and hydrogen is likely to play a significant role only with strong government support.

An array of potential improvements to new light-duty passenger vehicles conceivably could double their fuel economy by 2030. Aside from hybrid drivetrains, there can be substantial improvements in both gasoline and diesel engine technology, weight reduction through lightweight materials and improved designs, better aerodynamics and tires, improved transmissions, and so forth. However, a key issue will be the extent to which these technologies are used for reducing fuel consumption or instead to obtain other things—larger vehicles; better acceleration performance; more amenities such as four-wheel drive; and improved safety. The U.S. Environmental Protection Agency has estimated that the U.S. new car and light truck fleet's fuel economy in 2005 would have been 24 percent higher had the fleet remained at the weight and performance distribution it had in 1987. Instead, it became 27 percent heavier and 30 percent faster in 0–60 mph acceleration time—and fuel economy actually declined a bit. Although the U.S. may be an extreme case, this type of tradeoff of performance and size versus fuel economy is being made to some degree throughout the world.

A wide array of technologies exists to reduce GHG emissions in other transport areas. For example, an array of body shaping and other measures on inter-city freight trucks can sharply reduce aerodynamic drag; coupled with significant improvements in diesel technology, fuel economy improvements as high as 50 percent may be possible for high speed operation. Similarly, substantial improvements in efficiency are possible for trains and airplanes.

Biofuels can play a substantial role in reducing GHG emissions from all transport modes. A recent International Energy Agency study estimated that biofuels could substitute for 4–7 percent of transport fuel in 2030 and 13–25 percent by 2050 at costs less than U.S.$25/metric ton of CO_2. However, the higher values require substantial progress in developing the technology for using cellulosic materials (such as switchgrass and wood waste) as fuel feedstocks.

Policy

There is an array of potential policy tools that could help to reduce GHG emission growth throughout the transport sector. As noted above, in areas with rapid urbanization and transport systems in the early stage of development, good urban design, development of efficient public transport systems, and promotion of walking and biking can reduce the growth of personal vehicles while providing excellent mobility and access to services. These policies also have an important role to play in the United States and elsewhere in the industrialized world, although much of the die is cast in terms of dependence on personal vehicles and in the form of urban areas.

A key policy tool that is applicable worldwide is the fuel economy standard for personal vehicles. Such standards are now widely used, even in countries with much higher fuel prices and vehicle taxes than ours, and much better public transport systems. These have been effective in slowing the growth of oil use and GHG emissions, and they were effective in the United States—in consort with higher fuel prices—in raising new light-duty vehicle fuel economy from 13.1 mpg in 1975 to 22.1 mpg in 1987. Some form of fuel economy or CO_2 standard or agreement is now in place in Japan, the European Union, China, Australia, and elsewhere, and the State of California and a group of other States are attempting to establish their own CO_2 standards. In my personal view, the new attribute-based standard for light trucks recently established by the National Highway Traffic Safety Administration, based on a vehicle's "footprint" (wheelbase times track width) is worthy of close attention as a candidate for a standard for the combined fleet of cars and light trucks.

Taxation policies on fuel and vehicles can also play an important role. Many countries do heavily tax motor fuels and have lower rates of fuel consumption than countries with low taxes. However, vehicle travel demand, the demand for vehicles, and fuel use are not highly price elastic, so relatively high taxes are required to have major effects on fuel use and GHG emissions. A variety of transportation demand management (TDM) strategies can also reduce the use of personal vehicles and reduce GHG emissions.

Several of the "high potential" technologies that could allow sharp reductions in GHG emissions from transport will require substantial additional development, so government support of research and development activities aimed at these technologies is an important policy tool. Key technology areas include:

- Cellulosic biomass—production and sustainability
- Batteries for hybrids, plug-in hybrids and electric vehicles
- Aircraft engines and high efficiency aircraft structures (e.g., the blended wing concept)
- Hydrogen fuel cells
- Vehicle structural materials
- Advanced gasoline and diesel engines

Mitigation Potential

The IPCC estimates that the mitigation potential for the transport sector is about 1,600–2,550 million metric tons of CO_2 at carbon prices below $100/ton of CO_2. This estimate does not consider heavy-duty freight and transit vehicles, rail transport, shipping, and shifts from private vehicles to public transport and non-motorized travel. The estimate is highly uncertain, however, because of the limited number of studies of world transport mitigation potential and strong uncertainties about future oil prices and future progress in technology development. Key areas of uncertainty are biomass fuel production technology and biomass production sustainability in massive scale, and battery cost, lifetime, and energy storage capacity.

BIOGRAPHY FOR STEVEN E. PLOTKIN

Steve Plotkin is a staff scientist with Argonne National Laboratory's Center for Transportation Research, specializing in analysis of transportation energy efficiency. He has worked extensively on automobile fuel economy technology and policy as a consultant to the Department of Energy, and was a consultant to the National Research Council's study on the *Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards*. He is a lead author on the Intergovernmental Panel on Climate Change (IPCC) 2007 Assessment Report on Mitigating Climate Change. He was for 17 years a Senior Analyst and Senior Associate with the Energy Program of the Congressional Office of Technology Assessment (OTA) and prior to that he was an environmental engineer with the U.S. Environmental Protection Agency.

Mr. Plotkin has a BS degree in Civil Engineering from Columbia University, and a Master of Engineering (Aerospace) degree from Cornell University. He is the 2005 recipient of the Society of Automotive Engineers' Barry D. McNutt Ward for Excellence in Automotive Policy Analysis.

Chairman GORDON. Thank you, Mr. Plotkin. You gave us a lot to think about there.

And Dr. Pielke.

STATEMENT OF DR. ROGER A. PIELKE, JR., PROFESSOR OF ENVIRONMENTAL STUDIES PROGRAM AT THE UNIVERSITY OF COLORADO AND DIRECTOR OF THE CENTER FOR SCIENCE AND TECHNOLOGICAL POLICY RESEARCH

Dr. PIELKE. I thank the Chairman the Committee for the opportunity to offer testimony this morning. I just want to note before I get into my testimony that it was 16 years ago this week I walked into Rayburn 2320 as a graduate student intern under Congressman George Brown, and I have a great deal of appreciation for the work that everyone does here, particularly the staff and how important they are.

My testimony today is based entirely on the information provided in the Summaries for Policy-makers of Working Groups II and II of the IPCC. I begin with three assertions.

Number 1. Current debate over climate change represents a great opportunity to discuss what kind of future will result from our current decision.

Number 2. Working Group III indicates that the benefits of mitigation outweigh its costs, and based on this conclusion, mitigation should be a policy priority.

Number 3. Working Group II is concerned with one of the many pressing challenges to global well-being and emphasizes that greenhouse gas mitigation is only one of many avenues for confronting these challenges.

The problem that I am addressing today is that we may successfully meet the challenge of greenhouse gas mitigation but still fail in the broader effort to promote a sustainable future for our globalizing society.

In my written testimony I argue that effective progress on coping with climate impacts such as sea level rise, tropical diseases, and disaster impacts, requires a broad focus on sustainable development, including future development in the United States and other developed countries. I want to emphasize that nothing in this testimony or in any of my work on climate change over the past decade or more should be interpreted as being opposed to or somehow contrary to the mitigation of greenhouse gases. The main point is that a focus on control of carbon dioxide cannot substitute for a broader discussion of policies that will enable the most desirable futures.

And, indeed, this is one of the main messages of the IPCC, which is discussed in its Working Group II report, but which seems to be overlooked in the broader debate on climate change. Today I want to make sure that this message is clear.

The IPCC bases its work on four families of scenarios for the future, which it creatively named A1, A2, B1, and B2. The scenarios provide a basis for projecting our greenhouse gas emissions growth in the future as input to climate models, which use the projected future emissions as an input. The IPCC scenarios are thus alternative visions of how the future might evolve. The IPCC makes no claim about the relative probability of each scenario actually occurring.

In reality, of course, how the future evolves is the result of decisions that we make. In other words, by making decisions we make some futures more likely and some futures less likely.

Scenarios are also important because they allow for an analysis of the importance of decisions that lead to one scenario being realized versus another. A collection of decisions that lead to the realization of a particular scenario is a development pathway. Another way to think about this concept is as a broad notion of what is traditionally called adaptation.

Now, the essential message of my testimony can be seen in two figures, and if I could have the first figure put up.

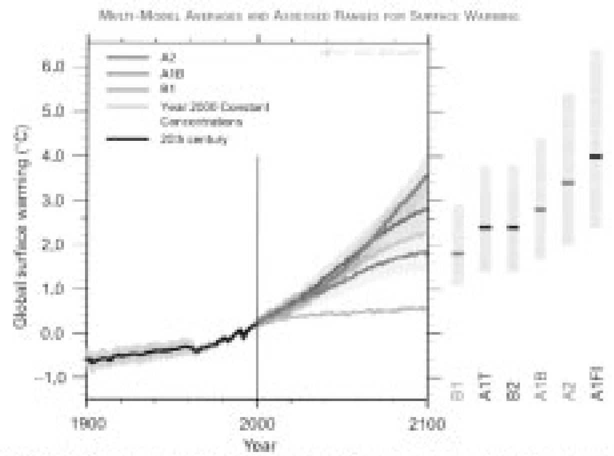


Figure 3. IPCC WG I SPM.5 appears with the following caption: "Solid lines are multi-model global averages of surface warming (relative to 1980–1999) for the scenarios A2, A1B and B1, shown as continuations of the 20th century simulations. Shading denotes the ±1 standard deviation range of individual model annual averages. The orange line is for the experiment where concentrations were held constant at year 2000 values. The grey bars at right indicate the best estimate (solid line within each bar) and the **likely** range assessed for the six SRES marker scenarios. The assessment of the best estimate and **likely** ranges in the grey bars includes the AOGCMs in the left part of the figure, as well as results from a hierarchy of independent models and observational constraints."

This figure shows the IPCC assumptions for global GDP growth. So you see with that gray bar there the IPCC starts with $20 trillion in 1990. Now, the IPCC, one of its scenarios, its lowest scenario, after you factor in the cost of damage from climate change, has the green bar showing future global GDP. So it anticipates that even with damage related to climate change we will be much wealthier. Under the IPCC assumptions, if we aggressively mitigate, we will be richer. That is represented by the red marginal addition.

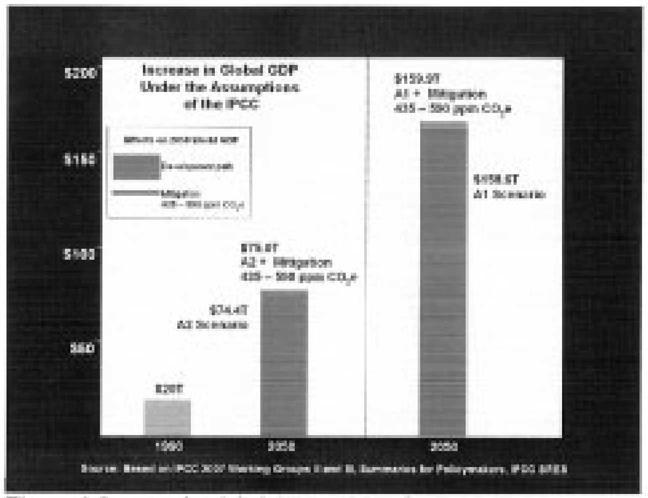


Figure 4. Increase in global GDP to 2050 for IPCC SRES scenarios A2 and A1 including damage costs of 5%. Also shown are the benefits of aggressive mitigation for each scenario

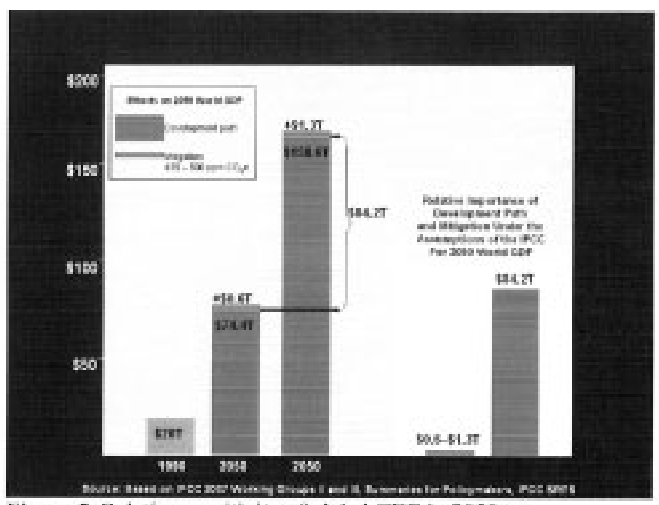


Figure 5. Relative sensitivity of global GDP in 2050 to aggressive mitigation and development path.

Now, if we look at another other IPCC scenarios, the one with the highest global GDP, that is this green bar on the far right, and indeed, under this scenario there is also benefits to aggressive mitigation. What I would like to emphasize is the difference between these two development pathways, these two scenarios, which is shown in this following graph. If you look at the subset, the little yellow box on the lower right there, the green bar represents the difference in global GDP based on pursuing one development pathway versus another. The red bar, the smaller red bar, represents the benefits of mitigation, and the point I want to make is that discussions of development pathways are far more important than discussions of mitigation. It is not a substitute for discussions of mitigation, but mitigation has to take place in this broader context.

The conclusions to take from this analysis are as follows. Number 1, mitigation provides benefits under all scenarios I discuss in my testimony and almost all scenarios presented by the IPCC.

Number 2, in all scenarios discussed here under the assumptions, conclusions, and metrics of value used by the IPCC, the importance of the development path far exceeds the importance of mitigation. Consequently, a focus on sustainable development should be central to any discussion of climate polices.

Adaptation provides the link between sustainable development and climate change by ensuring that the capacity of societies to develop is not compromised by the impacts of climate on their socioeconomic prospects.

Policy discussions about what sort of future we collectively wish to see unfold are myopic if focused only on greenhouse gas emissions. It would be the equivalent of a family discussion of their future focused only on their utility bill, ignoring their healthcare, education, housing, and everything else that matters.

It is true, of course, that a family that does not focus on its utility bill may find themselves in deep trouble. So a focus on the utility bill is indeed important, but that cannot be the entire focus. With respect to the current political debate about the world's future focused on energy policies, the analysis presented in my testimony based on the assumptions of the IPCC indicates that our focus needs to be much broader, on the path of development itself.

The most immediate way that the U.S. Congress can influence sustainable development as related to climate change would be to focus as intensively on the issue of adaptation as it has in recent months on mitigation. The Science Committee in particular can contribute to this agenda by ensuring that the Nation's climate research portfolio is organized in such a way so as to reflect the information needs of decision-makers facing choices about adaptation. For example, legislation proposed by Congressman Mark Udall and others on this committee, is notable for its efforts to more closely connect climate research with the needs of decision-makers.

In closing, the IPCC has great potential to serve as a unique resource for decision-makers. In my opinion, it will best reach that full potential not by replicating the important work of advocacy groups that seek to reduce the scope of choice available to decision-makers. Instead, the IPCC should serve to empower decision-makers by expanding their view and their options and to clearly distinguish the role of advisor from advocate and advisor from decision-maker.

Thank you very much.

[The prepared statement of Dr. Pielke follows:]

PREPARED STATEMENT OF ROGER A. PIELKE, JR.

Introduction

I thank the Chairman and the Committee for the opportunity to offer testimony this morning on *"The State of Climate Change Science 2007: The Findings of the Fourth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC), Working Group III: Mitigation of Climate Change."* I am a Professor of Environmental Studies at the University of Colorado and also Director of the University's Center for Science and Technology Policy Research.[1] My research focuses on the connections of science and decision-making. I also have been studying climate change science and policy for about 15 years. A short biography can be found at the end of my written testimony, including links to my publications. I am the author of a recently released book, *The Honest Broker: Making Sense of Science in Policy and Politics* (Cambridge University Press, 2007).

On a personal note it is a pleasure to appear before the Science and Technology Committee. In 1991 I had the opportunity to serve as an intern for the Committee under Chairman George Brown (D–CA) (and his staff director, Radford Byerly) and the experience greatly shaped my thinking and has influenced my career ever since.

Three Assertions

My testimony today is based entirely on the information provided in the Summaries for Policy-Makers (SPMs) of Working Groups (WGs) II and III of the Intergovernmental Panel on Climate Change (IPCC). My testimony today begins with three assertions:

- Current debate over climate change represents a great opportunity to discuss what kind of future will result from our current decisions. This opportunity is often missed because of a focus on the negative aspects of climate change or because debate degenerates into unhelpful partisan or ideological attacks.
- The IPCC WG III indicates that the benefits of mitigation outweigh its costs, and based on this conclusion, mitigation should be a policy priority. Of course, the exact details of mitigation policies, and in particular the time symmetry between costs and benefits, are not trivial.[2]
- The IPCC WG II is concerned with one of many pressing challenges to global well-being, and emphasizes greenhouse gas mitigation is only one of many avenues for confronting those challenges.[3] However, this important message often goes unappreciated in policy debates. We need to make certain that the focus on the issue of greenhouse gas emissions does not crowd out other important challenges.

What Is the Problem?

The problem is that we can successfully meet the challenge of greenhouse gas mitigation but still fail in the broader effort to promote a sustainable future for our globalizing society. In a commentary in *Nature,* Gwyn Prins, Steve Rayner, Dan Sarewitz and I argued that mitigation alone cannot solve many of the world's most pressing environmental problems, including many that are related to climate:[4]

> For example, in the Philippines, policy-makers have begun to acknowledge the flood threats posed by the gradual sea-level rise of one to three millimeters per year, projected to occur with climate change. At the same time, they remain oblivious to, or ignore, the main reason for increasing flood risk: excessive groundwater extraction, which is lowering the land surface by several centimeters to more than a decimeter per year.

[1] At the University of Colorado I am affiliated with CIRES, the Cooperative Institute for Research in Environmental Sciences, a joint institute of the University of Colorado and the National Oceanic and Atmospheric Administration (NOAA). The Center that I direct at CIRES has received research funding from a number of other federal research agencies, including NSF and NASA. I thank a number of colleagues who offered perspectives on early versions of this testimony. The views presented here are my own.

[2] I discuss this challenge in this testimony: Pielke, Jr., R.A., 2006. Statement to the Committee on Government Reform of the United States House of Representatives, Hearing on *Climate Change: Understanding the Degree of the Problem,* 20 July. *http://sciencepolicy.colorado.edu/admin/publication_files/resource-2466-2006.09.pdf*

[3] On this point see especially Chapter 20 of the forthcoming full AR4 WG II report.

[4] Pielke, Jr., R.A., Prins, G., Rayner, S. and Sarewitz, D., 2007. Lifting the taboo on adaptation. *Nature,* 445, 597–598. *http://sciencepolicy.colorado.edu/admin/publication_files/resource-2506-2007.11.pdf* See this paper for citations to the literature.

Similarly, non-climate factors are by far the most important drivers of increased risk to tropical disease. For instance, one study found that without taking into account climate change, the global population at risk from malaria would increase by 100 percent by 2080, whereas the effect of climate change would increase the risk of malaria by at most seven percent. Yet tropical disease risk is repeatedly invoked by climate-mitigation advocates as a key reason to curb emissions. In a world where political attention is limited, such distortions reinforce the current neglect of adaptation.

In another example, the threat of hurricane damages is often invoked in the climate debate as a justification for action on energy policies (e.g., see Figure 1 below), creating an expectation that future damages can somehow be effectively modulated according to atmospheric greenhouse gas concentrations. This is simply wrong. In a forthcoming paper I conclude:[5]

Figure 1. Promotional ad linking linking energy policy and hurricanes

. . .under a wide range of assumptions about future growth in wealth and population, and about the effects of human-caused climate change, in every case there is far greater potential to affect future losses by focusing attention on the societal conditions that generate vulnerability to losses. Efforts to modulate tropical cyclone intensities through climate stabilization policies have extremely limited potential to reduce future losses. This conclusion is robust across assumptions, even unrealistic assumptions about the timing and magnitude of emissions reductions policies on tropical cyclone behavior. The importance of the societal factors increases with the time horizon.

This does not mean that climate stabilization policies do not make sense or that policy-makers should ignore influences of human-caused climate change on tropical cyclone behavior. It does mean that efforts to justify emissions reductions based on future tropical cyclone damages are misleading at best, given that available alternatives have far greater potential to achieve reductions in damage. The most effective policies in the face of tropical cyclones have been and will continue to be adaptive in nature, and thus should play a prominent role in any comprehensive approach to climate policy.

The lesson from these three examples is that effective progress on coping with sea level rise, tropical diseases, and disaster impacts requires a broad focus on sustainable development. I wish to emphasize that nothing in this testimony—or in any of my work on climate change over the past decade or more—should be interpreted as being opposed to or somehow contrary to the mitigation of greenhouse gases. The main point is that a focus of control of carbon dioxide cannot substitute for a broader discussion of policies that will enable the most desirable futures. And this is in-

[5] Pielke, Jr., R.A., 2007 (accepted). Future Economic Damage from Tropical Cyclones: Sensitivities to Societal and Climate Changes, Proceedings of the Philosophical Transactions of the Royal Society. *http://sciencepolicy.colorado.edu/admin/publication_files/resource-2517-2007.14.pdf*

deed one of the main messages of the IPCC, which is discussed in its Working Group II report, but which seems to be overlooked in the broader debate on climate change. Today I want to make sure that this message is clear.

Which Path to the Future?

The IPCC bases its work on four families of scenarios for future which are named A1, A2, B1, and B2.[6] The scenarios provide a basis for projecting how greenhouse gas emissions might grow into the future as input to climate models which use the projected future emissions as a key input. Figure 2 (below) illustrates the four scenarios as presented by the IPCC with respect to two dimensions.

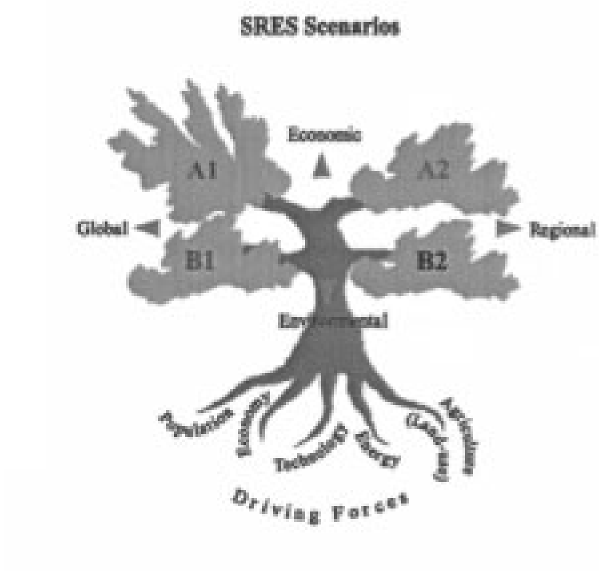


Figure 2. IPCC Scenarios.
http://www.grida.no/climate/ipcc/emission/1-4.htm

But the scenarios are much more than projections of emissions. The IPCC describes them as follows:

> Scenarios are images of the future, or alternative futures. They are neither predictions nor forecasts. Rather, each scenario is one alternative image of how the future might unfold. A set of scenarios assists in the understanding of possible future developments of complex systems. Some systems, those that are well understood and for which complete information is available, can be modeled with some certainty, as is frequently the case in the physical sciences, and their future states predicted. However, many physical and social systems are poorly understood, and information on the relevant variables is so incomplete that they can be appreciated only through intuition and are best communicated by images and stories. Prediction is not possible in such cases.[7]

The IPCC scenarios are thus alternative visions about how the future might evolve. The IPCC makes no claim about the relative probability of each scenario actually occurring.

> The SRES scenarios are descriptive and should not be construed as desirable or undesirable in their own right. They are built as descriptions of possible, rather than preferred, developments. They represent pertinent, plausible, alter-

[6] *http://www.grida.no/climate/ipcc/emission*
[7] *http://www.grida.no/climate/ipcc/emission/025.htm*

native futures. . .. Good scenarios are challenging and court controversy, since not everybody is comfortable with every scenario, but used intelligently they allow policies and strategies to be designed in a more robust way.[8]

In reality, of course, how the future evolves is a result of decisions that we make. In other words, by making decisions we make some futures more likely and others less likely.

Both IPCC WGs II and III included a short description of the four families of scenarios. The text box on the following page reproduces the summary descriptions of the scenarios from WG III.

The scenarios are important because they allow for a sensitivity analysis of the importance of decisions that lead to one scenario being realized versus another. The collection of decisions that lead to the realization of a particular scenario is a "development pathway." Another way to think about this concept is as a broad conception of what is traditionally called "adaptation."

Development Pathways Matter a Great Deal for Societal Outcomes

There are multiple measures that can be used to measure the relative worth of a particular societal outcome. The SPMs of IPCC WGs II and III emphasize wealth as measured by global Gross Domestic Product (GDP). So that is the measure used here. The IPCC justifies its use of this metric in one its chapters in its SRES report on as follows:

> Income is not an end in itself, but a way to enable human choices, or to foreclose them in the case of poverty. Therefore, levels of per capita income (GDP or GNP) have been widely used as a measure of the degree of economic development, as in many instances such levels correlate closely (as lead or lag indicator) with other indicators and dimensions of social development, such as mortality, nutrition, and access to basic services, etc. Average income values also do not indicate the distribution of income, which is an important quantity. Composite measures, such as the UN Human Development Index, are also used in historical analyses (see Box 3–1). Note, however, that the overall nature of scenario results may not vary much even if some other measure could be used, because often-used components, such as literacy rates, are generally correlated with income levels.
>
> In fact, per capita income is the (and often only) development indicator used in the literature for long-term energy and GHG emissions scenarios. This explains why this review chapter, while recognizing the importance of alternative dimensions and indicators to describe long-term human development, almost exclusively embraces an economic perspective.[9]

Even though the IPCC has chosen to focus on GDP as a primary indicator of relevant societal outcomes, WG II in particular recognizes that decisions are made for a wide range of reasons, wealth being only one of them. Also, the analysis presented below relies on quantitative estimates of the costs of climate change damage and climate mitigation. The IPCC states that both types of estimates are clouded by considerable uncertainties and thus although the analysis presented below relies on specific, quantitative assumptions and conclusions of the IPCC, it should be understood in terms of its qualitative implications.

The SRES scenarios describe very different worlds:

[8] *http://www.grida.no/climate/ipcc/emission/025.htm*
[9] *http://www.grida.no/climate/ipcc/emission/057.htm*

IPCC Working Group III SPM, text Box SPM.1: *The emission scenarios of the IPCC Special Report on Emission Scenarios (SRES)*

A1. The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non fossil energy sources (A1T), or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end use technologies).

A2. The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.

B1. The B1 storyline and scenario family describes a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives.

B2. The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

An illustrative scenario was chosen for each of the six scenario groups A1B, A1FI, A1T, A2, B1 and B2. All should be considered equally sound.

The SRES scenarios do not include additional climate initiatives, which means that no scenarios are included that explicitly assume implementation of the United Nations Framework Convention on Climate Change or the emissions targets of the Kyoto Protocol.

All four storylines and scenario families describe future worlds that are generally more affluent compared to the current situation. They range from very rapid economic growth and technologic change to high levels of environmental protection, from low-to-high global populations, and from high-to-low GHG emissions. Perhaps more importantly, all the storylines describe dynamic changes and transitions in generally different directions. The storylines do not include specific climate-change policies, but they do include numerous other socio-economic developments and non-climate environmental policies. As time progresses, the storylines diverge from each other in many of their characteristic features.[10]

In terms of specific economic numbers, the SRES report begins with 1990 global GDP estimated at $20 trillion (T) in 1990 dollars. It then projects future world GDP based on different estimates of future population and per capita growth rates. The SRES growth assumptions[11] (in parentheses below) result in the following baseline global GDP values for 2050:

A1 = (3.6 percent) $167.0T
A2 = (2.3 percent) $78.3T
B1 = (3.1 percent) $124.9T
B2 = (2.8 percent) $104.9T

These estimates do not include the costs of damage associated with unmitigated climate change. IPCC WG II provides an estimate of future damages for a tempera-

[10] *http://www.grida.no/climate/ipcc/emission/090.htm*
[11] *http://www.grida.no/climate/ipcc/emission/100.htm*

ture rise of four degrees Celsius: “global mean losses could be 1–5 percent GDP for 4°C of warming.”[12] IPCC Working Group I indicates that 4°C of warming is highly unlikely to occur by 2050 under any of the scenarios (Figure 3 below).[13] So an assumption of five percent reduction in GDP in 2050, the top of the WG II range, very likely overstates the amount of damage projected by the IPCC for 2050.

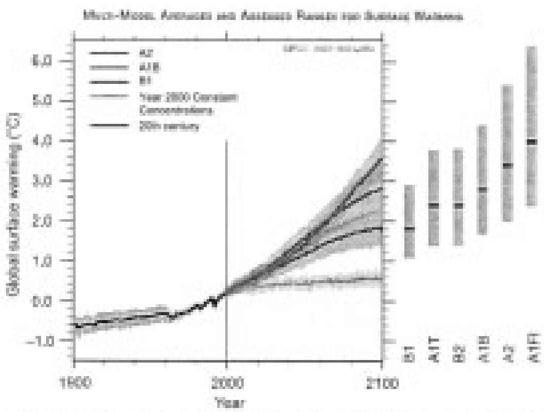


Figure 3. IPCC WG I SPM.5 appears with the following caption: “Solid lines are multi-model global averages of surface warming (relative to 1980–1999) for the scenarios A2, A1B and B1, shown as continuations of the 20th century simulations. Shading denotes the ±1 standard deviation range of individual model annual averages. The orange line is for the experiment where concentrations were held constant at year 2000 values. The grey bars at right indicate the best estimate (solid line within each bar) and the **likely** range assessed for the six SRES marker scenarios. The assessment of the best estimate and **likely** ranges in the grey bars includes the AOGCMs in the left part of the figure, as well as results from a hierarchy of independent models and observational constraints.”

Reducing the baseline global GDP by five percent results in the following totals:

A1 = $158.6T
A2 = $74.4T
B1 = $118.7T
B2 = $99.6T

If we assume that all of the five percent in damage costs can be avoid through aggressive mitigation then net 2050 global GDP would be the following totals:[14]

A1 = $159.9T
A2 = $75.0T
B1 = $119.6T
B2 = $100.4T

These figures allow for a comparison of the sensitivity of future global GDP to mitigation policies alone versus a more comprehensive focus on differences between different development paths. Figures 4 and 5 show this comparison.

The first column of Figure 4 shows (in grey) the $20T used by the IPCC for 1990. The second column shows (in green) 2050 global GDP ($74.4T) under the IPCC growth and damage assumptions for the A2 scenario which has the lowest total GDP of the four scenario families. On top of this bar is a smaller (red) bar showing the additional benefit ($0.6T = $75.0T–$74.6T)) to global GDP for aggressive mitigation that avoids damage. On the right hand side of the figure is a third column that indicates 2050 global GDP ($84.2T = $158.6T–$74.4T) under the IPCC growth and

[12] *http://www.ipcc.ch/SPM13apr07.pdf* at p. 16.
[13] *http://www.ipcc.ch/WG1_SPM_17Apr07.pdf* at p. 14.
[14] The costs of aggressive mitigation (i.e., stabilization at 445–590) are estimated by IPCC WG III to be at most three percent of GDP in 2030 and 5.5 percent of GDP in 2050 according to WG III SPM tables SPM.4 and SPM.6. Because these values are at the top of the IPCC range, and the IPCC does not provide a mid-range value, I arbitrarily cut them in half to 1.5 percent and 2.75 percent in the analysis presented here.

damage assumptions for the A1 scenario which has the highest total GDP of the four scenario families. Similarly, on top of this bar is a smaller (red) bar showing the additional benefit ($1.3T = $159.9–$158.6) to global GDP for aggressive mitigation that avoids damage.[15]

Figure 5 shows the relative sensitivity of future global GDP to aggressive mitigation policies and development pathway. The inset figure (yellow box) on the lower right shows that aggressive mitigation provides a benefit to global GDP of $0.6 or $1.3T (depending on scenario) and choice of development pathway provides a benefit of up to $84.4T (i.e., the difference between the GDP in scenario A1 and scenario A2, = $158.6–$74.4T). **It must be underscored that this analysis reflects assumptions explicit in the IPCC assessments.**

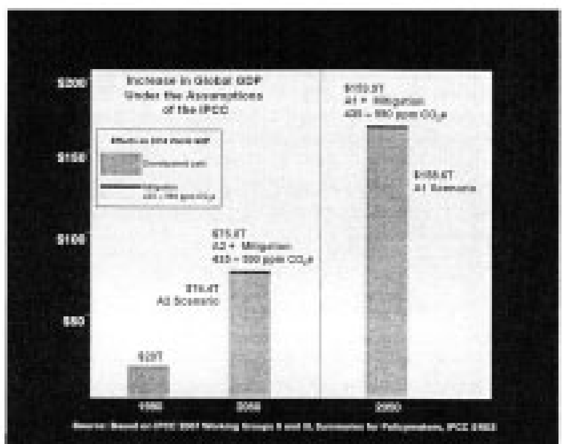


Figure 4. Increase in global GDP to 2050 for IPCC SRES scenarios A2 and A1 including damage costs of 5%. Also shown are the benefits of aggressive mitigation for each scenario

[15] Instead assuming that damage will reduce GDP by five percent annually then the benefit to aggressive mitigation would be $16.5T under A1 and $5.1T under A2. At 2.5 percent the values are $8.5T and $1.6T respectively.

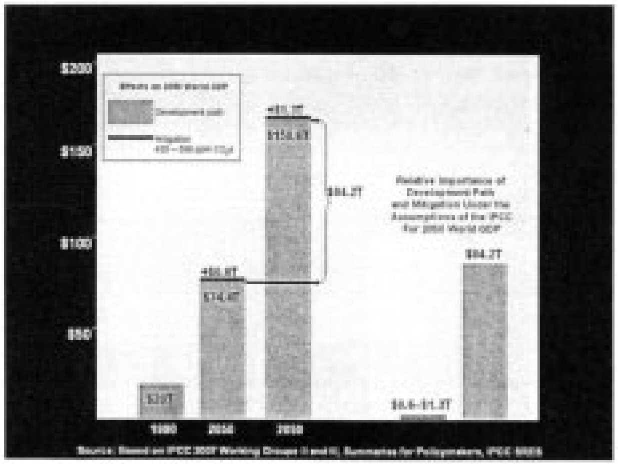


Figure 5. Relative sensitivity of global GDP in 2050 to aggressive mitigation and development path.

Because the IPCC estimates of damage related to anthropogenic climate change and mitigation costs are highly uncertain, it is worth examining a wide range of assumptions in this analysis. Such an examination leads to qualitatively similar results across assumptions about damage and mitigation. For instance, if one instead uses global per capita GDP rather than total GDP (as shown in Table 1 below[16]) the largest difference between development paths (i.e., between A1 and A2 = $11,388) is about *76 times* larger than the largest benefit associated with aggressive mitigation (A1 = $150).

Table 1. Per capita GDP for IPCC SRES scenarios under the assumptions of 5% total damage in 2050 under BAU and 1.5% (in 2030) and 2.75% (in 2050) cost of aggressive mitigation to prevent damage (as above).

SRES Scenario	2050 per capita GDP BAU (with damage of 5% of total)	2050 GDP Aggressive Mitigation (445-570 ppm CO_2e)
A1	$18,024	$18,174
A2	$6,636	$6,639
B1	$13,483	$13,595
B2	$9,962	$10,045

These results hold qualitatively if one uses the assumptions of the Stern Review report[17] on climate change which included much larger estimated damage associated with unmitigated emissions (of a five percent–20 percent reduction in *annual* global GDP starting immediately) with aggressive stabilization policies of costing three percent annually, as summarized in Tables 2 and 3.

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[16] The IPCC SRES discussion of global population growth can be found at *http://www.grida.no/climate/ipcc/emission/051.htm*

[17] The Stern Review Report on the Economics of Climate Change, *http://www.hm-treasury.gov.uk/independent—reviews/stern_review_economics_climate_change/stern_review_report.cfm*

Table 2. World per capita GDP for IPCC SRES scenarios under the assumptions of Stern Review of 20% damage per year under BAU and 3% annual cost of mitigation to prevent damage.

SRES Scenario	2050 per capita GDP BAU (with damage of 5% of GDP annually)[18]	2050 GDP Aggressive Mitigation (3% of GDP annually)
A1	$17,880	$18,470
A2	$6,900	$6,990
B1	$13,530	$13,900
B2	$10, 230	$10,450

[18] In Tables 2 and 3 the calculations use the IPCC assumptions of 1990 world per capita GDP of $3,700 and growth rates to 2050, see: *http://www.grida.no/climate/ipcc/emission/100.htm*

Table 3. World per capita GDP for SRES scenarios under assumptions of Stern Review of 20% damage per year and 3% annual cost of mitigation.

SRES Scenario	2050 per capita GDP BAU (with damage of 20% of GDP annually)	2050 GDP Aggressive Mitigation (3% of GDP annually)
A1	$13,980	$18,470
A2	$6,260	$6,990
B1	$11,050	$13,900
B2	$8,720	$10,450

For five percent annual damage the largest difference between development paths (i.e., between A1 and A2 = $10,980) is about 19 times larger than the largest benefit associated with aggressive mitigation (for A1 = $590). For 20 percent annual damage the largest difference between development paths (i.e., between A1 and A2 = $7,720) is about 1.7 times larger than the largest benefit associated with aggressive mitigation (for A1 = $4,490).

What does this analysis mean?

The conclusions to take from this analysis are as follows:

1. **Mitigation provides benefits under all scenarios discussed here, and almost all scenarios presented by the IPCC. According to the IPCC these benefits increase as the time horizon extends further into the future.**
2. **In all scenarios discussed here, under the assumptions, conclusions, and metrics of value used by the IPCC, the importance of the development path far exceeds the importance of mitigation. Consequently, a focus on sustainable development should be central to any discussion of climate policies. This point is in fact reflected especially by IPCC WG II, but often it is overlooked in broader discussions of climate change policy.**
3. **Adaptation provides the link between sustainable development and climate change, by ensuring that the capacity of societies to develop is not compromised by the impacts of climate on their socioeconomic prospects.**

To reiterate, nothing in this testimony should be interpreted as being opposed to or contrary to the mitigation of greenhouse gases. To the contrary, under all scenarios discussed here the benefits of mitigation exceed its costs. Mitigation is good policy, and many decision-makers are now coming to understand that it is good politics, as well.

However, policy discussions about what sort of future we collectively wish to see unfold are myopic if focused only on greenhouse gas emissions. It would be the equivalent of a family discussion of their future focused only on their utility bill, ignoring their health care, education, housing, and everything else that matters (or simply how their utility bill is related to their health, education, housing, and everything else that matters). It is true of course that a family that does not focus on its utility bill may find themselves in deep trouble. So a focus on the utility bill is indeed important, but that cannot be the entire focus. With respect to the current political debate about the world's future focused on energy polices, the analysis presented in this testimony based on the assumptions of IPCC indicates that our focus needs to be much broader—on the path of development itself. A discussion of greenhouse gas mitigation cannot substitute for that broader discussion, but should be a part of it.

The IPCC WG II SPM recognizes the importance of a discussion of development pathways explicitly:

> . . .the projected impacts of climate change can vary greatly due to the development pathway assumed. For example, there may be large differences in regional population, income and technological development under alternative scenarios, which are often a strong determinant of the level of vulnerability to climate change.
>
> To illustrate, in a number of recent studies of global impacts of climate change on food supply, risk of coastal flooding and water scarcity, the projected number of people affected is considerably greater under the A2-type scenario of development (characterized by relatively low per capita income and large population growth) than under other SRES futures. This difference is largely explained, not by differences in changes of climate, but by differences in vulnerability.[19]

And so too does WG III SPM:

> Making development more sustainable by changing development paths can make a major contribution to climate change mitigation, but implementation may require resources to overcome multiple barriers. . .
>
> Changes in development paths emerge from the interactions of public and private decision processes involving government, business and civil society, many of which are not traditionally considered as climate policy. This process is most effective when actors participate equitably and decentralized decision-making processes are coordinated. . .
>
> Making development more sustainable can enhance both mitigative and adaptive capacity, and reduce emissions and vulnerability to climate change.[20]

Until our discussions of climate change are broadened to include a more comprehensive focus on development pathways, it is unlikely that we will make wise decisions about the future, including those about the emissions of greenhouse gases. Put somewhat differently, poor decisions about development can ruin the benefits of wise decisions about mitigation.

Recommendations

The most immediate way that the U.S. Congress can influence sustainable development as related to climate change would be to focus as intensively on the issue of adaptation as it has on mitigation. Adaptation allows societies to maintain their vitality in the face of climate variability and change, and also the pressures caused by development itself. Effective policies with respect to sea level rise, tropical diseases, and the impacts of natural disasters would complement progress on mitigation and provide benefits in the near-term, since these issues are already of considerable importance.

The Science Committee in particular can contribute to this agenda by ensuring that the Nation's climate research portfolio is organized in such a way so as to reflect the information needs of decision-makers facing choices about adaptation. For example, legislation proposed by Congressman Mark Udall (D–CO) is notable for its efforts to more closely connect climate research with the needs of decision-makers.[21]

In closing, the IPCC has great potential to serve as a unique resource for decision-makers. In my opinion, it will best reach its full potential not by replicating the important work of advocacy groups that seek to reduce the scope of choice available to decision-makers. Instead, the IPCC should serve to empower decision-makers by

[19] *http://www.ipcc.ch/SPM13apr07.pdf,* p. 18

[20] *http://www.ipcc.ch/SPM040507.pdf,* p. 33–34.

[21] See, *http://democrats.science.house.gov/Media/File/Commdocs/hearings/2007/energy/03may/hearing_charter.pdf*

expanding their view and their options in order to clearly distinguish the role of advisor from advocate, and advisor from decision-maker.[22]

BIOGRAPHY FOR ROGER A. PIELKE, JR.

Roger A. Pielke, Jr. has been on the faculty of the University of Colorado since 2001 and is a Professor in the Environmental Studies Program and a Fellow of the Cooperative Institute for Research in Environmental Sciences (CIRES). At CIRES, Roger serves as the Director of the Center for Science and Technology Policy Research. Roger's current areas of interest include understanding disasters and climate change, the politicization of science, decision-making under uncertainty, and policy education for scientists. In 2006 Roger received the Eduard Brückner Prize in Munich, Germany for outstanding achievement in interdisciplinary climate research. Before joining the University of Colorado, from 1993–2001 Roger was a Scientist at the National Center for Atmospheric Research. Roger serves on various editorial boards and advisory committees, and is the author of numerous articles and essays. He is also author, co-author or co-editor of five books. Roger has degrees in mathematics, public policy, and political science, all from the University of Colorado. His most recent book is titled: *The Honest Broker: Making Sense of Science in Policy and Politics* published by Cambridge University Press.

DISCUSSION

BIOFUELS

Chairman GORDON. Thank you, and welcome back, Dr. Pielke.

At this point we will open our first round of questions, and the Chair recognizes himself for five minutes.

Mr. Plotkin, in your discussion of transportation, you had, I think, some positive views on biofuels. What are, in your opinion, are the type of breakthroughs that we need to make to really fully maximize those biofuels?

Mr. PLOTKIN. I think there are two issues we have got to focus on primarily. The first is that if we really are serious about getting significant amounts of biofuels into worldwide use and in use in the United States, we have got to move past corn-based ethanol and move to cellulosic-based fuels. And it may be ethanol, but it may also be a variety of other fuels for transportation. And in order to do that we have got to bring the costs way down, because right now they are unaffordable. So that is number one. We have to continue and maybe intensify our research and development.

And second, we really have to focus on what the effects will be of transforming very large quantities of our land and land elsewhere in the world into what is basically going to be a monocrop. Crops like these are nice from the standpoint of not needing a lot of pesticides and fertilizer, at least not to the same extent as road crops do, but on the other hand, they are vulnerable as monocrops to new kinds of pests and problems like that. We really don't know at this point what will happen if we transform a large portion of our land into those crops, so we need to study that.

FUEL ECONOMY STANDARDS IN CHINA

Chairman GORDON. And in your testimony, and I will quote here, you say, "Some form of fuel economy or CO_2 standard or agreement is now in place in Japan, the European Union, China, Australia,

[22] Pielke, Jr., R.A. 2007. *The Honest Broker: Making Sense of Science in Policy and Politics* (Cambridge University Press).

and elsewhere in the—and the State of California and a group of other states are attempting to establish their own CO_2 standards." What are they doing in China now?

Dr. PLOTKIN. The Chinese have weight-based standards that are somewhat similar to the standards that the Japanese have, which are also based on weight. That is the larger the vehicle, the less fuel economy they must achieve, which is, you know, pretty logical. It is obviously a lot harder to get high fuel economy with a big SUV than it is with a smaller mini car.

The difference in the Chinese standards is that they apply to every segment of the market. That is, you can't switch credits from one part of the market to the other, which makes it a lot less flexible for their manufacturers to conform with that than in a situation where you can have some cars more efficient and some cars a little less, and as long as the total fleet meets the target.

INTERNATIONAL EFFORTS

Chairman GORDON. And Dr. Pizer, you mentioned engaging in international reassessment. There are some that are concerned that the United States, you know, that we can't afford to take on this whole burden. And that we would be foolish, I guess you might say, economically to try to do that, unless you get China and other countries to participate. I don't necessarily advocate that, but that is what some would suggest. What is your suggestion on how we can engage other nations?

Dr. PIZER. Well, I think the first step is to have a reasonable domestic policy. I think it is a lot easier to convince people to come along with something once you have already demonstrated leadership. We already have, the European Union has in place an emissions trading program to deal with their emissions, and my guess is if we took action, most of the other developed countries would take action.

Engaging poorer countries like China and India that are growing and have a lot of development needs I think is going to be harder. I think there are a variety of ways we could do that, and just to mention four ways right off the bat, one is through expanded use of project-based crediting, which is currently the way the protocol works. Two would be to try to get them to recognize policy reforms along the lines of the energy efficiency improvements that Mr. Plotkin mentioned. They would be in their interests in reduced emissions. Third would be to try to twist their arm and get them to take on CAPS through, you know, other things they care about internationally or just their own concern about the problem. And then fourth would be to try to engage their private sector on deals that would benefit particular entities like trying to get the national gas company in China to become interested in getting a pipeline to China that would eventually reduce their emissions.

So I think there are a variety of different ways that we can go about it, but probably the first step is a more serious U.S. policy.

THE ADVANCED RESEARCH PROJECTS AGENCY–ENERGY (ARPA–E)

Chairman GORDON. And you had mentioned in your statement without prodding ARPA–E and the benefits. What do you see as the benefits of ARPA–E?

Dr. PIZER. Well, I think one of the problems on the technology front has just been the absence of a sustained commitment to develop major new technologies in the energy arena. I mean, if you look at the pattern of public investment in energy R&D over the past 30 years, it has been very unstable, and it has been declining. And a lot of that hasn't been very flexible in terms of how it has been applied. So I think having a very serious and sustained management and support for energy research would go a long way towards dealing with one of the real pillars of the future of this problem.

Chairman GORDON. Thank you and all the other witnesses.

Mr. Hall, I now recognize you for five minutes.

ADAPTATION AND MITIGATION STRATEGIES

Mr. HALL. Thank you, Mr. Chairman.

Dr. Pizer, you, I heard your presentation as an argument for increased gasoline tax. Was that, is that correct? Did I understand you correctly?

Dr. PIZER. I think you have to recognize that if you are going to put into place a flexible policy to try to reduce emissions, one of the ways that works is by raising prices to try to encourage conservation. Now, if you actually look at what we are talking about in 2030, relative to where we are now, it is actually depending on what happens over the next 30 years. It might be an increase or a decrease relative to current levels, but it would certainly be an increase relative to what they would be otherwise.

Mr. HALL. And you recommend that?

Dr. PIZER. I think if we are serious about reducing a use of fossil fuels, and we want to do it flexibly, yeah. You have to raise the price of fossil fuels.

Mr. HALL. Is that what you mean by saying engage other nations and show some leadership?

Dr. PIZER. I think there is a number of pieces to it, but one would be a serious market-based policy. The other would be the support of technology.

Mr. HALL. And the leadership you want us to show is by going ahead and expending the money. What presumptions did you use on China's position when you arrived at that conclusion?

Dr. PIZER. I am sorry. Presumption about——

Mr. HALL. About China, about their participation, about their emissions. You surely entered into some presumptions on your own when you arrived at the figures that you have given us and you chose the level of the year that you chose.

Dr. PIZER. Well, I was basing the numbers that I was using on the numbers that were actually analyzed in the IPCC report. Now, if you are asking kind of my personal opinion about this, you know, I think that——

Mr. HALL. I will take that.

Dr. PIZER. Okay. You know, I think a policy where the U.S. starts with something modest, and we could discuss what modest means, and we expect China to follow us, you know, at some interval, maybe five years or 10 years, and if they don't, we either go back on what we are doing or we, you know, enact some sort of legislation to protect our domestic industries. That would probably make sense. But I think we do have to, I think if we are going to expect China to go forward, given their standard of living is a fraction of what ours is right now, we have to exercise some sort of leadership.

Mr. HALL. You mean go forward by taking American jobs?

Dr. PIZER. I don't necessarily think that the policies that are being talked about would cost jobs. I mean, there would be switching jobs.

Mr. HALL. Do you use that in your presumption in arriving at the conclusions you have given us here today?

Dr. PIZER. Presumption that it would cost jobs?

Mr. HALL. Absolutely.

Dr. PIZER. No. I don't think it would cost jobs.

Mr. HALL. You don't think so?

Dr. PIZER. No. It would be switching jobs.

Mr. HALL. Well, let us see here. Let me see how reasonable you are. You looked at the three concentrations of greenhouse gases and then estimated it both the year 2030, and the year 2050, as to what it would cost to achieve these concentrations. And you used the lowest concentration, didn't you, in giving us your figure of three percent?

Dr. PIZER. The three percent is associated with the most stringent stabilization goals. Yes.

Mr. HALL. Based on year 2030.

Dr. PIZER. In 2030. That is correct.

Mr. HALL. Yeah. But on the year 2050, what would your estimate be on the percent?

Dr. PIZER. I could look at the numbers, but I am going to guess it is probably about around three percent as well. It is a pretty constant number.

Mr. HALL. No change in——

Dr. PIZER. It might be a little bit higher, but I don't think it is substantially. Is it five percent? Okay.

Mr. HALL. Well, I used the middle concentration of 2050, and these studies say that would be four percent as I stated. Do you disagree with that?

Dr. PIZER. I would not say——

Mr. HALL. You would stay with three no matter if it is 2020, or 2050, or 2090.

Dr. PIZER. One of the things I, the first point I really emphasized was the uncertainty we have predicting the costs. I would certainly agree that the costs could be as high as four percent in 2050. That is correct.

THE IPCC PROCESS

Mr. HALL. Okay. I appreciate that.

Dr. Pielke, what do you think of the IPCC process?

Dr. PIELKE. Overall I think the IPCC process is a sincere effort to collect and bring the best knowledge available from the science community, the impacts community, the economics community to decision-makers. I do think that the IPCC process suffers from a lack of connection with the stated needs from decision-makers. It would be nice to have the process start with decision-makers saying here is what information we need. Here are the questions we have, and that would shape the production of the reports.

The first IPCC assessment in 1990, had its Working Group III focus on policy options. That changed over time. Now it is focused on mitigation, and I think something was lost in that process where we don't talk about a wide range of options now.

Mr. HALL. What changes would you recommend for the future reports?

Dr. PIELKE. I would suggest something that I have often called for a "Working Group IV," where we take the science, the impacts, the economics, and we integrate it. And we provide you folks, policy-makers, with a smorgasbord of options all the way from doing nothing to aggressive mitigation, adaptation, different forms, with the idea that their job is to provide you with what you can do, and your job is to decide what you should do.

ADAPTATION AND MITIGATION STRATEGIES IN CHINA

Mr. HALL. I will ask the panel, did you all use any presumptions that China was going to change their course when you arrived at the three percent?

Dr. PIZER. One of the things I mentioned was that all the studies, at least in the section I worked on, generally presumed that the whole world, you know, at some point in the future when the studies are done, are all working together. The cost studies are based on the idea of global participation. Yes.

Mr. HALL. That would be wonderful, wouldn't it? Yes, sir.

Dr. LEVINE. Outside IPCC, I studied China energy, and China has embarked on a path of reducing their energy intensity by 20 percent over the next five years. Now, they are not doing that for CO_2 mitigation. They are doing that because they can't afford to be investing that much in energy, and they are very concerned about local environmental impacts.

Mr. HALL. Isn't it impossible to get to the three percent you all talked about if China alone stays on their present course?

Dr. LEVINE. Well, they are——

Mr. HALL. Their present course and that is why we have to judge them on. They have given us no indication they are going to change or help us try to cleanse the world.

Dr. LEVINE. No. They have changed courses. Their energy GDP ratio in this past year has declined considerably. I do give you a lot of credence for being concerned about how well they do, but they are trying very hard to change course.

Mr. HALL. I sure hope so. I am out of time. Thank you.

Chairman GORDON. Dr. McNerney is recognized for five minutes.

GREEN EMPLOYMENT OPPORTUNITIES

Mr. MCNERNEY. Thank you, Mr. Chairman. I want to thank the panel for coming out here and sharing your expertise with us.

I am going to direct my first comment to something that Dr. Pizer said. The cost of mitigation to keep temperature rise at two degrees Centigrade or less, which is already a very large increase and has a very large associated global economic cost, has a very wide possible range of outcome from plus four to minus six percent, which means that if we mitigate, we will create new sections of the economy which, some of which will focus on our rural communities, creating a new prosperity in our rural areas which are now having difficulties.

And if we, the cost of inaction or inadequate action will very likely be very, very much higher than that. So just in terms of probabilities it is a good outcome to go ahead and make the investment in mitigation.

Now, Mr. Plotkin's comments on the transportation reinforced that assessment that mitigation will improve the economy. So my colleagues on the other side of the table often focus on the taxes and particularly on gas tax, but the panel's testimony indicates to me that policies can move forward without relying very much on gas tax. Can you comment on that, Dr. Pielke?

Dr. PIELKE. Yeah.

Mr. MCNERNEY. Well, can you comment on my assessment that investing in mitigation will actually improve the economy, especially the rural economy.

Dr. PIELKE. Yeah. I guess my view on that is at some point we should stop debating what the economy and the climate system is going to be in 2030, or 2050, and start doing things. And by doing things I suggest that we start taking actions. States are taking actions, cities are taking actions on greenhouse gases, and we should evaluate them, and those things that have net benefits, we should do a lot more of those things, and those things that don't work and have costs, we should do less.

And I think the notion of improving the economies in rural locations or fostering technological innovation that stimulates the economy are all plausible, and they are all supported, I think, in the economics literature, but we won't know in the real world until we actually start doing things.

BUILDING EFFICIENCY

Mr. MCNERNEY. Okay. I am going to switch a little bit to Mr. Levine. Building efficiency seems to be a very critical part of eliminating or reducing CO_2, but I don't know exactly what would be effective in terms of building mitigating or how we get our people that own houses to invest in the things they need to, and how do we change buildings? Is there a new technology on the horizon that will make this more transparent, this approach more transparent?

Dr. LEVINE. Well, the first thing you want to do is put policies in place, and California is probably the best example. California has been able to keep energy use per capita in buildings constant since 1972, whereas the rest of the country has increased by I think around 70 percent. They have done it through aggressive appliance efficiency standards, which has the advantage of educating consumers. They only get to buy cost-effective, efficient appliances. They have had very aggressive, I should say we, I am from California, so are you. We have had very aggressive utility demand management programs, which means the utilities go in and offer rebates and offer fixes within houses to improve efficiency within the house. That has been very effective because it goes into areas where consumers really just need help. And then we have had a successful set of building codes.

So without any new technology, and there are, of course, new technologies, we have been able to keep energy use per capita constant in the state for, how many years is that? Forty years. Now, there are new technologies, and some of them have come in almost automatically. There was a big push not too many years ago to get builders to build their houses tighter when it was discovered that leaking houses caused large losses in energy use. And that has been very successful. It has been successful through training programs among builders, word of mouth.

We now have this sort of unfortunate situation or I guess you could say the glass is half full, fortunate situation where we have compact fluorescents, and it turns out that while they save three-fourths of the energy and they perform very well, very well, very few of the sockets in our houses in California have them. Well, we need to do something about that. It is a trivial matter. The utilities did a sensational job in California and elsewhere in getting more efficient fluorescent lamps in.

So those are the kinds of things you can do in the near-term. In the longer-term it is a bit of a tougher problem for commercial buildings because you really want to have much more advanced technology to have integrated systems that control and give you feedback on the buildings, and for that R&D is needed, demonstration programs are needed. But we could get to, close to 0 energy buildings over time.

Chairman GORDON. Thank you, Dr. Levine. Mr. Sensenbrenner.

MORE ON INTERNATIONAL EFFORTS

Mr. SENSENBRENNER. Thank you very much. I have heard an awful lot of testimony this morning about raising the price of energy. I have heard the word tax. I have heard the word, substantial tax. I have heard the words increasing the cost whether it doesn't involve a tax to raise the price of energy. And I have heard questions from at least two of my colleagues relative to what happens if we do that and China does nothing.

Just by way of historical note since I am the gray beard around here, in 1993, my Democratic colleagues voted for Al Gore's carbon tax, and then they voted for a big package that included an increase in the gasoline tax, and then in the next election we won 52 seats and took over control of the House of Representatives. So I hope that the tax word is falling on very productive ears on the other side of the desk.

That being said, I went to Kyoto as chair of the delegation in 1997, and the entire delegation met with the Chinese, and they said no way, no how are they going to reduce any carbon emissions, and they have maintained that position up to and including their submission to the meeting of IPCC Group III in Bangkok. All of us are getting hit by our constituents relative to the outsourcing of jobs to countries like China and India.

And how do you expect our manufacturing sector in particular to compete if there is a huge increase in the energy that they need to make their products here but no increase in energy costs in China and India? These are decisions that we as policy-makers are going to have to consider if we are to accept any of these recommendations.

Anybody want to take a whack at that? Dr. Levine.

Dr. LEVINE. I think we have a bigger issue with the exchange rate with China, and if we could get the exchange rate in an appropriate parity, I think many of these other issues would be second order. We have much higher energy prices in Japan, in Europe, and you know——

Mr. SENSENBRENNER. Well, you know, if I can reclaim my time, the Japanese economy has been in a recession for the better part of the last 15 years and only has recently turned around. Most European countries have got double digit unemployment. I don't think any of us, whether we are Democrats or Republicans, want to consign our economy to that kind of a fate. The real issue is how do you deal with this without China and India being on board? And what is the IPCC doing to be able to come up with a matrix that would encourage the Chinese and the Indians to be on board, because they would view it as in their economic best interest. I haven't heard anything lately on that.

Dr. LEVINE. IPCC doesn't do anything. They are very advisory, and this is within the realm of——

Mr. SENSENBRENNER. But IPCC is giving advice to policy-makers. We are policy-makers. We are policy-makers where our existence here is dependent upon our voters sending us here. And listening to the prescriptions that you and the panels at the previous hearings have had, I am supposed to be the happy bearer of good news saying we are going to increase your taxes, we are going to double your electric bill, we are going to double your natural gas bill, and we are not going to make China do anything. So when everybody gets thrown out of work, you know, then I guess we will increase the deficit to provide some kind of an adjustment program for you.

Now, that is not a winning political matrix for anybody, is it?

Dr. PIZER. If I could just respond to the first point that you were talking about. It definitely does not work for the U.S. to pursue a policy that is adverse for its economy period. But it is also not sensible for the U.S. to do something that raises its energy prices if China and India don't do anything, and all of our industry just goes over there and emits over there. It doesn't help the economy, it doesn't help the environment.

So the question is what do we do in order to bring China and India along, and I guess my argument is that we have to do a lot of different things, and one of them is probably take a modest first step. I don't think we do something that has dramatic impacts, but we do have to take something that says that we are serious and convince them to come along with us.

Mr. SENSENBRENNER. Thank you. My time is up.

Chairman GORDON. Mr. Carnahan is recognized.

EFFICIENCY TECHNOLOGIES

Mr. CARNAHAN. Thank you, Mr. Chairman, and thank this panel. It has been very insightful and inspiring to hear some of the possibilities that are there and pulling this information together can help us with our public policy.

I will tell a little bit about our experience in St. Louis. We had a prominent building company there, a prominent construction company, that renovated an older structure, has gotten the platinum lead certification, the top, I guess, green building certification you can get internationally. Was so successful in doing that with their own building, and the business executives there talk about the economic benefit to their company, the long-term savings they are going to have with those things they have designed into the building, they actually created a green building design subdivision of the company, and they are going out and selling this. And we have had a lot of international visitors come to St. Louis to see this, to see how it can be done, and so, you know, this is a winning business model, a winning economic model that people are using, and we seen that locally at home.

And I wanted to ask Dr. Levine about, you know, the testimony about by 2030, about 30 percent of the emissions could be saved. And really if you could just list off what are some of the technologies or practices that help us get to that point that we need to be focusing on.

Dr. LEVINE. The biggest growth areas in both residential and commercial buildings is plug loads, things you simply plug into wall outlets and when they are not on, they are hot, and that is when they are not producing anything useful, they are producing heat. What we need to do is to develop a chip so that when they are plugged into the wall, they are effectively not doing anything, and you are saving electricity.

Mr. CARNAHAN. That would be something built into the plug itself or into the appliance?

Dr. LEVINE. Into the gizmo that you plug into the wall.

Mr. CARNAHAN. The plug itself.

Dr. LEVINE. The plug itself.

Mr. CARNAHAN. Okay.

Dr. LEVINE. Yeah. And right now the estimate is that you have the equivalent of a refrigerator worth of, one to three refrigerators worth of those things in your house. So they are a very large savings that you just aren't aware of.

Mr. CARNAHAN. Has that chip been developed? Is that——

Dr. LEVINE. It is under development and not yet available in all applications. You know, you have set-top boxes on your TVs that are using 20 plus watts, and they could be using two to three watts. We need to get industry agreement to cut them down to two to three watts, and that is a process that is going on right now.

Mr. CARNAHAN. Where is that being done?

Dr. LEVINE. Well, EPA has an Energy Star Program. We are involved in it and trying to congeal the manufacturers. The California Energy Commission is trying to make a pest of itself in getting appropriate attention. The windows can be better. We are working on the next generation of windows that are dynamic windows that respond to different temperatures outside. I think for residential buildings insulation is in pretty good shape. There is still ways of reducing air infiltration, particularly in the ductwork in residential buildings, and there are now technologies to do that. And I don't want to go at length on this, but I do want to say that the, I want to say two more things.

Commercial buildings are actually a very unfortunate situation, large commercial buildings. They have had very, very little attention on R&D, and the opportunities are very great. They are systems, and so it is very hard to do R&D in a system instead of widget. And so we need to treat them as systems, and we need to work on them as systems, and we need to do demonstrations with control systems and the building interacting.

And then, of course, for the longer-term you want to have building-integrated floatable tank systems in buildings. That is not available now, but it will be in due course one hopes.

MORE ON BUILDING EFFICIENCY

Chairman GORDON. Thank you, Dr. Levine.

Just for the information of the Science Committee Members, former Chairman Boller a few years ago asked the Carnegie Mellon University to do a research project on the Science Committee and energy efficiency. We have picked that up and talking with the Speaker this fall the Science Committee, all of our rooms will be made a model for the Capitol in terms of energy efficiency.

Later you are going to see, I have got quite a bit of legislation, which is concerning energy efficiency within commercial and residential buildings, most of which will come through this committee, almost all of which is off-the-shelf technology now that is not, you know, anything that is way outside. The commercial residential section is the largest user of energy, and I think there is a lot of things we can do.

One thing I think is of interest, and I think certainly the Federal Government should take the lead, but what will happen oftentimes is an agency will say, well, you know, we don't have enough money as it is, so we can't waste it, not waste money, but we can't use money on insulation or more expensive light bulbs because our budget is too tight. So we want to create a revolving fund so that agencies can come to this revolving fund and with a plan of "X" amount, again, off-the-shelf types of insulation or changes, that will cost a dollar, and some expert will say that the savings can, you can repay that with your energy savings over three years or four years, and so they will pay that back in. So we are going to do, I think, some creative things. Again, off-the-shelf things that should hopefully continue our unanimous—yes, Mr. Bilbray.

Mr. BILBRAY. Mr. Chairman, I come from a state from where we only use two forms of energy from an air pollution point of view. We talk about putting in the light bulbs and everything, but as long as the United States Government in Washington is generating its electricity out of the dirtiest technology and the highest emitter of carbon, I really find it interesting that we are talking about five percent reduction doing this and this when the elephant in the room is not being addressed. And the fact is that we have, since

1992, the Federal Government has tried to decommission zero-emission generators, such as hydroelectric. But as long as we are looking down the pipe of coal-burning Congressional facility over here, I really have a problem with us having a moral high grounds, setting an example for the rest of America. My little old constituency out there, well, the fact that what Congress does to generate the electricity for this facility, you would go to prison in California for.

So I just want to say as we talk about all these neat things, I am still in culture shock when I come back here and see those coal trains coming in, and I know it is an inappropriate thing. It is not politically correct to say right now, but I just say again, we have got to confront this issue, and we have got to address the source of the emissions, which is the power plants.

And I yield back. Thank you, Mr. Chairman.

Chairman GORDON. Thank you. We want to see you come out of shock, and that is the reason that the Speaker has already introduced a Green Capitol Initiative. That is the reason that we got approval to do the science room. The, certainly the coal-fired plant is of real interest. I would point out that most of the, what looks like the gray stuff that is coming up is steam.

But you are right. And there needs to be a change, and I think, and the Federal Government needs to take the lead, and you are going to see that start to occur.

And Mr. Rohrabacher is next.

ANTHROPOGENIC CAUSES OF CLIMATE CHANGE

Mr. ROHRABACHER. Thank you, Mr. Chairman, and I certainly appreciate my colleague from California who along with this Member of Congress enjoys transportation vehicles that have totally renewable, based on renewable energy in terms of title and wave-related energy sources. We both, of course, live on the ocean.

Let me just note, and then we will go into a more detailed discussion about it right now, what we are talking about is based on the idea that manmade global warming is a reality, and of course that I totally reject. And I might add I have put on the record numerous scientists from MIT and other major universities throughout the world who disagree with that and think that it is basically being used as a football to push other agendas. That is the analogy I guess having a football to push agendas but as a method of pushing other agenda.

I would like to put a quote on the record here by Timothy Ball, who is, of course, a professor of climatology at University of Winnipeg. "I, believe it or not, global warming is not due to human contribution of carbon dioxide. This, in fact, is the greatest deception in the history of science. We are wasting time, energy, and trillions of dollars while creating unnecessary fear and consternation over an issue with no scientific justification."

Let me add that Dr. Ball's observation is not different than I say than many, numerous other scientists who now have been just totally ignored in the public debate in order to move forward with these very revolutionary concepts of what we should be doing to curtail or change the economic way, and the technological way that we manage our society.

Back to today's hearing about what we are really talking about is IPCC and what was recommended there. I have a quote here from Dr. Christopher Landsea, who was taught by NOAA and received his doctoral degree from Colorado State University in atmospheric sciences. He was part of the IPCC effort, and he said, "I am withdrawing," meaning from the IPCC, "because I have come to view the part of the IPCC to which my expertise is relevant as having become politicized. In addition, when I have raised my concerns to the IPCC leadership, the response was simply to dismiss my concerns, which I have seen so often where people just want to say the debate is over, and not handle the actual specific arguments that are being presented by those who question this."

And then I go on with Dr. Landsea, "I personally cannot in good faith continue to contribute to a process that I view as being both motivated by pre-conceived agenda and being scientifically unsound." Now, first of all, I would like to ask the witnesses that were part of the IPCC process is Dr. Landsea just some guy who is dishonest about this, or is he someone who has raised some serious concerns about the IPCC process?

Chairman GORDON. Mr. Rohrabacher, we have two votes coming up. What I would suggest is the witnesses to answer your question. We will then go to Mr. Lampson and see if we can get that one in, and then witnesses, if you will excuse us for about 30 minutes, we have to go vote, and we will be back.

Mr. ROHRABACHER. Mr. Chairman, does that mean that possibly I could have the rest of my five minutes when we come back?

Chairman GORDON. Do you want to start all over, or you could let them, you had a minute, 30 seconds left if you would like for them to complete.

Mr. ROHRABACHER. Thank you. Go right ahead and answer and then I have got one other thing to put on the record.

Mr. PLOTKIN. Well, first of all, we were working on a different part of the assessment. I guess your gentleman was working on the science part, the first part. We are working on mitigation. There are a lot of people involved. It occasionally got sort of chaotic. I did not feel that it was a political process at all, and it is also a process that is, I come from an agency, an office of technology assessment, which had a really extensive review process. This was far more extensive than that, and that in my career, that was the most intensive.

So I think that a lot of that is filtered out if it gets into the system anyway.

Mr. ROHRABACHER. We have one scientist who was part of it who felt that it was totally compromised.

Mr. PLOTKIN. Part of a different part. I have no idea what went on, and I don't think any of us do——

Mr. ROHRABACHER. Let me just——

Mr. PLOTKIN.—on that particular part of the analysis.

Mr. ROHRABACHER.—for the record I am going to put this article into the record from *Newsweek Magazine* by Richard Lindzen, who is an MIT professor, very respected man, who says, "The current alarm rests on the false assumptions that not only that we live in a perfect world temperatures but also that our warming forecasts for the year 2040, are somehow more reliable than the weatherman's forecast for next week."

And let me know even today from what your testimony is, I heard the words, best guesses, I think were the words that I jotted down, and in terms of what these models that we are talking about. We should not be doing something that will affect the standard of living of people who in our country, middle Americans who earn $50,000 a year, affect them dramatically, which is what I have heard, based on these type of charts which are being called into question, these types of projections that are being called into question by some of the top scientific minds on the planet who are being ignored in this debate.

Chairman GORDON. Thank you, Mr. Rohrabacher.

And Chairman Lampson, if you would conclude this section.

MITIGATION OBSTACLES

Mr. LAMPSON. Thank you, Mr. Chairman. I may give you back a little of time. I will try.

I would like for Dr. Levine to talk for just a minute about maybe more you have already perhaps already done some of this, but obstacles that keep commercially-viable technologies from wider-spread use in the country. And I think that your Summary for Policy-makers includes a table with a number of building relevant mitigation strategies that are available. What are some of the obstacles? Why aren't more people more anxious to do those kinds of things?

Mr. LEVINE. I think one of the biggest problems is transaction costs. How much time do you have to shop? How much time do you have to shop to get the most efficient product, and how do you know that it really is the most efficient product? And so people really have limited time.

Another aspect of that is availability of technology. Turns out interestingly that appliance manufacturers were not making the most efficient appliances that would sell on the market because they had a marketing strategy that gave them a better return by not doing do. And so until appliance standards came in, they had no incentive to put more efficient technology onto the market.

You have got extremely complex design processes for commercial buildings, where you have engineers doing one thing and architects doing another thing, and they don't talk to each other. And everybody gets paid based on how much time it takes to do the design, and nobody gets paid on how much energy savings you get in the design. So the design process itself if flawed. It is often difficult to get extra financing for more efficient products.

Mr. LAMPSON. And we trust the efficiency guides that are placed on appliances today?

Dr. LEVINE. I think we do now. Yeah. The EPA has done a terrific job in its Energy Star Program so that that problem has in good measure been overcome. And also Appliance Standards I think has done a very good job.

Mr. LAMPSON. Let me——

Dr. LEVINE. But, you know, it is sort of, it is a matter of trust. You are dealing with these gizmos. You don't know what they are, and whom do you trust? You have salespeople at one end and the other end. It is a tough job.

Mr. LAMPSON. Indeed. Let me just ask Dr. Plotkin if I may. You made a comment about if the U.S. new car and light truck fleets, fuel economy would have been 24 percent higher had we not changed the weight of the vehicles. Would you comment on that and also on the weight or body shape changes as far as automobiles are concerned?

Mr. PLOTKIN. Well, I think in vehicles there is a little, something a little different happening than in buildings. If you, I don't think there is a lot of tradeoff in buildings with energy savings. You got a more efficient air conditioner, you are going to use it to save energy. Unless you decide to chill your house a little bit more. But in vehicles, making a vehicle more efficient or a technology that can make a vehicle more efficient can be used either for fuel economy or it can be used to improve performance or make the vehicle bigger. That is sort of similar to a house. You can make the house bigger, obviously, if you can produce the energy savings.

Chairman GORDON. Will the gentleman yield back? I am sorry. We are getting close on time.

Mr. LAMPSON. Yes.

Chairman GORDON. Let me make this suggestion. It is my understanding that we have a motion to adjourn, which will be followed by 10 minutes of debate on the National Defense Authorization Bill, and you know how long 10 minutes can go. And then we will have two votes. So what I would suggest, I don't mean to be overly inconvenient to you folks, but I would suggest let us go vote and then come back here between the debate, you know, starting with, you know, we can get several questions in, and Mr. Plotkin, I understand you have to catch a plane, and your presence has been appreciated, and you are excused, and we will, if there is no objection we are going to come back after this vote, and if we can finish, we will.

[Recess.]

Chairman GORDON. The Committee is back in session, and Dr. Ehlers is recognized.

MITIGATION COSTS

Mr. EHLERS. Thank you, Mr. Chairman. My first question is for Dr. Pielke. First of all, I appreciated your suggestion that the concentration of IPCC should be on recommendations for policy-makers. I appreciate the work they do, but it would be helpful to have it translated to meet our needs. On your charts, perhaps I didn't quite understand it, but you showed very small mitigation costs compared to economic growth, as I recall. Did I understand that correctly?

Dr. PIELKE. That is correct.

Mr. EHLERS. Okay. Now, were you implying that we can forget about mitigation because the costs are so small compared to our economic growth, or are you trying to say we should mitigate *because* the cost is really so small compared to economic growth?

Dr. PIELKE. I guess I would say "small" is a relative term because we are talking about trillions of dollars and so if you can benefit the global economy by a few trillion dollars, then we should do that. So the message from that is that mitigation provides a net benefit. But the broader, bigger picture is that, that is the not the only set of decisions we have to make about our long-term economic future. And the difference between the low-GDP future envisioned by the IPCC and the high-GDP future is something like $80 trillion, which is about 80 times larger than that mitigation benefit. I guess my overarching point is that we should be paying as much attention to achieving that $80 trillion as we are to achieving that $1 or $2 trillion by 2050.

DEVELOPING COUNTRIES

Mr. EHLERS. Okay. Now, how do you see this relating to less developed countries or even countries which are rapidly developing such as China or India? How do you see their decision-makers reacting to this?

Dr. PIELKE. Yes, I see this as the key question, and I appreciate that you asked it because in the discussion earlier about China, I think this point was missed. China is not something to fear, the rapid development in China is an opportunity. China is using enormous amounts of expensive energy. If the United States through an innovation agenda, investing in the development of cleaner, cheaper, energy technologies gets there first, then the Chinese are going to rush to buy our products. So it seems to me that if we think about not just climate change but about innovation, competitiveness, as a much bigger picture, the development in China is nothing to be afraid of or that it should limit our action. It is really an opportunity, particularly for the science community, to invest money in innovation that puts us out in front so that our economy grows, and we capture some of that $80 trillion in growth.

Mr. EHLERS. Well, I totally agree with you on that. I am dismayed that some of my colleagues here in the Congress seem intent on making China into an enemy whereas I like to see them as a potential customer, not just as a supplier but as a customer of us. A good example might be in terms of what IPCC worries about would be nuclear development in our country. We have not done a good job of developing nuclear plants. But if we made an effort at it, we would have a very large market in China. Right now I am afraid that market is going to go to France or some other countries, simply because we are not latching onto it. So I appreciate your comment on that.

MORE ON BUILDING EFFICIENCY

Also a general comment for both of you, if you wish to comment. Mr. Chairman, you made some comment about how we must not look at the energy savings just in terms of cost; we must look at the other benefits as well, the other issues involved. I certainly agree with that. I have been gung-ho about energy efficiency for years. In fact, back in the mid-seventies, I got fed up with the insulation in my house. It was done according to standard practices, but I redid it myself, you know, plugged the air holes where the cold air, in Michigan you get a lot of cold air was getting in. It filtered down from the attic into the walls from every opening that that you made for electrical outlets and everything. I sealed everything off, sprayed the insulation back in, and shaved one-third off my utility bill. Now, that is a very substantial savings. However, if I had hired someone to do it, it would not have been much of a saving. But the fact that I did it myself, I earned a lot of money very easily. I don't know how we address that. If either of you have any ideas of how we can change either the system or change the mentality so people are more prepared to spend money on energy conservation. And I am not talking just about individuals. I find the business sector that way too. I have never understood why in the business community they are totally gung-ho about efficiency of operation, efficiency of distribution and all that, but you talk energy efficiency to them, this is a silly, fuzzy-headed, knee-jerk liberal idea and it is still money. And when EPA did the Green Lights Program, it was a real eye opener to industry that they could see that much money just by replacing the lighting. So I don't know if either of you have any comments on that.

Dr. PIZER. Well, I think one possibility is improved information programs, probably through the utility companies, to make people both more aware of these opportunities that exist, as well as providing them with loans potentially to try to—if they don't actually want to install the insulation themselves, to hire someone to do it. I think that is a big piece of it. Another possibility is to think about tighter building codes. That is usually something that is done more at the State and local level, but, you know, requiring builders to actually to use more efficient—more insulation when they are building houses would go a long way towards dealing with that problem.

Mr. EHLERS. Well, actually that is the most cost-effective way to do it is through a building code because redoing a house later is far more expensive than doing it right the first time.

Chairman GORDON. The gentleman's time has expired.

Mr. EHLERS. Just one last comment on the utilities. The difficulty with the utilities is that they make more money by selling more energy so you have to totally restructure the reimbursement mechanism for the utility.

I yield back.

Chairman GORDON. Thank you, sir.

Mr. Smith is recognized.

CHINA'S COAL ENERGY PRODUCTION

Mr. SMITH. Thank you. I regret that our witnesses are disappearing, but I will try to make it quick. Perhaps anyone on the panel can respond, but earlier statements suggested that we need to get away from corn ethanol and transfer to switchgrass. If either of you can speak to the energy content or renewable energy content of a bushel of switchgrass compared to a bushel of corn, if you could speak to that. Also, a statement was made by the gentleman who had to catch an airplane about mono-cropping relating to renewable energy, if you could comment on that. And then also we heard earlier from my colleagues about coal and about China's approach, and if you have the data on China's coal energy production now, how many plants are due to come online, whether or not it is clean-coal technology, and then also, I don't know, maybe it was Dr. Levine who said that China is already striving to be I think more energy efficient or something. Anyway, in my estimation, this is suggesting that market-based approaches are being engaged in China.

I realize that is a lot of questions for a short period of time, but I do want to speak to the issue that market-based approaches are working a great deal. I find it very hard to imagine that my good friend from Michigan accuses businesses of ignoring the cost savings of energy efficiency, and those are my words. I don't want to change your words. But already the desire to engage in capitalist economy many times works. I am afraid—I visited India, and the environment there is very, very concerning to me. And then I come home—and Mr. Sensenbrenner certainly spoke to the fact that we get beaten up politically over all these jobs going to Asia and to think that they would be exempt when we would not be. So if the panel would care to respond, perhaps Dr. Pizer, if you would begin?

Dr. PIZER. I am going to skip the switchgrass versus corn ethanol. That is not really something I could speak well to. Unfortunately, Mr. Plotkin had to leave. Let me talk a little bit about, I guess, coal, because that is something I know a little more about. There was a recent study done by MIT, the MIT coal study, which really looked at this problem in a lot of detail. And I think one of the conclusions of that study is that coal is an incredibly important part of our energy mix as well as of China's. And to answer your specific question, I think they are building something like the equivalent of one 500-megawatt plant every couple of weeks basically to feed their rising demand for energy, and these are not the most efficient plants in the world that they are building.

So the recommendation of the study, recognizing the importance of the climate change issue, was really to call for a large research effort on capture and storage technology for coal plants. Because if we are going to continue to use coal in this country, and China is going to continue to use coal as well, that is going to be a really critical technology. So at this point, it is something that needs—there needs to be a regulatory framework. There needs to be large-scale demonstration projects and that is kind of the key story for coal. Dr. Levine might be able to speak to the energy efficiency programs in China a little bit better than I could. I guess I would say on the trade side, that keeps coming up, for a modest program to get started, the consequences for trade are in the noise. I mean, there are a lot of things that are going on that are problems for American industry and we need to really seriously work on those problems but I do think that it is possible to get started and eventually get China along with us without having an adverse impact on jobs in the United States.

Mr. SMITH. If I might interject, also on the taxation suggestions, that taxing energy would lead to more conservation. Certainly that can be the case, but I would suggest—I can't remember, and I apologize, which member of the panel suggested that recycling tax dollars would lead to great economic results. Would you suggest that the same dollar in taxes would leverage better results than a dollar—the same amount in the private sector with capitalist objectives?

Dr. PIZER. I think the point that was being referred to was a general theory of taxation. Tax—when you tax something it generally discourages it because it costs more, and if we have a choice, usually we like to tax things that are bad like pollution as opposed to taxing things that are good like labor and capital. And so the obvious point is that if we were to switch off of some of our taxes on labor and capital and put more tax on pollution like carbon dioxide emissions, we could actually increase the efficiency of the tax system, and that is a benefit to society.

Mr. SMITH. Dr. Levine, while you were out of the room I was inquiring about China. I think you made some statements about China's efforts already underway in terms of more efficiency, and I am assuming that you meant more environmentally friendly. Now, it is my understanding and as Dr. Pizer pointed out as well, that new coal plants are coming online in China without clean-coal technology that make our efforts seem pretty pristine. Would you speak to that?

Dr. LEVINE. Yeah. I would disagree a little bit with Dr. Pizer. Most of the coal plants coming into China are at least efficient, but they are not designed for carbon capture and storage. Neither are ours. And so we find ourselves in exactly the same situation. The problem in China is that they are building so many. They are building—they have this tremendous construction activity in coal-fired power plants in China, and this is frightening.

Now, what is to be done about it? The best thing to be done about it is to cut demand, and the Chinese have been slow to move in that direction. Up until 2000, they had been effective in cutting the growth and demand, and then it got away from them. They have now embarked on a program to cut the growth in energy intensity by 30 percent in five years. This is a remarkable goal. It is not only a goal. They have organized their industry, and they have given quotas to industries. They have given quotas to cities. They have put governors under pressure where if they don't do the right things, they stand to lose their jobs. They are attempting to create a bureaucracy that will once again provide incentives and no doubt punishments for accomplishing these objectives.

Chairman GORDON. The gentleman's time has expired. Vice Chair Lipinski is recognized.

ENERGY EFFICIENCY PRIORITIES

Mr. LIPINSKI. Thank you, Mr. Chairman. I would like to thank all our witnesses for their testimony today. I think that what we really need to, of course, focus on first is a very low-hanging fruit, and last night I was in the Rayburn garage, and I saw them putting in CFLs and was, you know, happy to see that as part of our Green Capitol Initiative. I have an amendment today of the DOD Authorization Bill to require the DOD to use high-efficiency bulbs where practicable. I also have a bill to require GSA buildings to use high-efficiency bulbs, put in high-efficiency bulbs when they are replacing bulbs. It seems that high-efficiency lighting is certainly such an easy way to, you know, save energy and you also save money, which is not something that you always find when you are saving energy.

That leads to my question here. All the recommendations that you have given, I appreciate hearing all these and hearing your expert testimony on them. What I would like to ask for is prioritization of these, you know, ways to go about, you know, helping reduce greenhouse gases and saving energy. How would you prioritize them? Like I said, I would think you go after the low-hanging fruit first, things which are less costly and save the most, and, you know, just balancing those things out. What do you think? And I will ask—I will start with asking Dr. Levine. Just quickly what would you prioritize that we here do first to work on this problem?

Dr. LEVINE. Well, the highest priority is efficiency. You do well in buildings, you can do very well in industry, not so widely known, and you heard from Steve Plotkin that we have a long way that we can go in transportation at low cost or net benefit.

Mr. LIPINSKI. Now, do we——

Dr. LEVINE. Those are the first things you do.

Mr. LIPINSKI. In terms of efficiency, what type of requirements—obviously you could talk CAFE standards with automobiles or what other ways do we get there to be more efficiency in various industries?

Dr. LEVINE. Well, those ultimately are political questions.

Mr. LIPINSKI. Well, that is why we are asking you for what the easiest way, you know, has the most impact.

Dr. LEVINE. Look, for industry my own personal preference would be to have industry agree to voluntary standards they take seriously. I think they can do it. I think you have seen it done in other countries, but this is sector wide. This is not, you know, plant by plant. For cars, you know, auto fuel economy standards, alternatives to gasoline. I have already talked about, I think, what the best policies are for buildings. I think when you get into the supply side, you are going to talk about some taxes and R&D, and you have to talk about R&D for efficiency as well, and you would like to recycle whatever the taxes are into R&D.

Mr. LIPINSKI. Okay. Dr. Pizer, one or two things?

Dr. PIZER. Yeah. I think I am a little bit more skeptical maybe with all due respect to Dr. Levine about the voluntary programs. The work that I and some colleagues have done suggest that there are some opportunities to get reductions and improvements in energy efficiency from voluntary programs, but they are usually limited to maybe five to ten percent. And if you really want serious activities, in the long run you are going to have to have something stronger, although five or ten percent wouldn't be a bad start, I guess.

The other thing that I think is a really important priority is sending signals to businesses so that they invest in new technologies and R&D, and I think that, you know, there are a variety of different ways to try to send that signal to business, but one of them is to suggest that the future is going to be somewhat different. If we really care about greenhouse gas emissions and the future is going to be about reducing those emissions in more and more serious ways, we need to convince business of that. Because if they keep making the same investments to improve conventional technologies, then we are never going to get the investment in the newer technologies that we need.

Mr. LIPINSKI. Thank you.

Chairman GORDON. If the gentleman would yield back then, Ms. Biggert is recognized, and we would like to—has the 15 minutes started? Okay. You know, I would like for our three remaining Members to have a chance the best you can here in these next 10 minutes to get your questions in.

Ms. BIGGERT. I will be short.

I know that Dr. Ehlers mentioned nuclear energy, and I think that is something that we really have to look at and what happens all the time is we look at the short-term and then don't move ahead with the nuclear, particularly when the gas prices go down. We seem to be lulled back into not looking at reducing our dependence on foreign oil and gas. So I think that that always has to be in forefront, and you know, we are talking about what, $2 billion probably to build another nuclear plant, but there are companies now who are already looking at getting the licensing and things. So I think that they are moving ahead.

A few years back then-Secretary of Energy, Spence Abraham, came to my district and to Argonne to look at the fuel cell for the hydrogen cars, and it was a big fuel cell, and he said, how long is this going to take before we will see it in cars. And I have already driven a hydrogen car around the streets of Washington, which is kind of scary because it is a $1 million car right now, and I don't drive around the streets of Washington that often. But I think as we move ahead, I was a little disappointed to hear that we haven't done anything, because I think EPAct, the 2005 energy bill, really had a lot in it. Unfortunately, everybody focused on the fact that we were for oil and gas, the tax credits, but there were a lot of tax credits. For example, we have a bill in the Energy and Environment Subcommittee for contractors, for architects who develop an energy-efficient building. I think we are moving ahead so much, and I don't know whether we need to combine that all into this one big project, but the President has the Advanced Energy Proposal and GNEP for nuclear, and so I think what you are doing is great. I think we need to look, say that we are doing these things and to find the ways to, you know, increase the need for it, increase the visibility of our plans because it is crucial.

But—so I am not going to ask a question. I am just going to make a statement. I yield back.

Chairman GORDON. Thank you, Ms. Biggert, and Mr. Bilbray is next.

NUCLEAR ENERGY

Mr. BILBRAY. Yes, Mr. Chairman. Gentlemen, I hear about the retrofitting and whatever, and I am just trying to picture in my years at air resources in California, California reduced its emissions by 50 percent. The air is twice as clean now as it was 20 years ago with twice as much population. There is no way we would have done that talking about retrofit. Stationary sources are where we have made the major reductions.

When it comes down to zero generators, have you guys specifically addressed the transformation from fossil fuels to nukes, either fission or fusion?

Dr. PIZER. I think most of the studies of stabilization have a hard time doing that without some increased role of nuclear power. Certainly the higher-end estimates are, you know, that is what a lot of times drives it is constraints on nuclear power. There are obviously a lot of problems with nuclear power as the previous person mentioned, but those are probably going to have to be dealt with if we are really serious.

The other big——

Mr. BILBRAY. Before you go——

Dr. PIZER. Sorry.

Mr. BILBRAY.—to the problems, what is the cost comparison between nuclear and other alternative, zero generation facilities?

Dr. PIZER. For base load, and my colleagues here can correct me, but for base load I don't think there really is an alternative right now for zero emissions. I mean, unless you are talking about expanded higher power, things like wind and photovoltaics and centralized solar power, you know, are not going to be cheaper, and wind isn't really base loads. So, you know, I think that that really is the alternative. Over the longer run I think people are very excited or hope for coal with capture and storage.

Mr. BILBRAY. And what?

Dr. PIZER. Coal with capture and storage.

Mr. BILBRAY. Well, that is an interesting thing, because I will tell you something. We talk about capture and storage. It is tough enough to find a disposal site within one State. When we talk about putting it two miles down with three-State jurisdiction and then people will raise later, what about this, the questions. I just think the capture and storage is sort of being treated as if it is not issue. It is a huge issue and regulatorily it is a huge issue.

Mr. Chairman, just, I know my time is—we are on short time.

Chairman GORDON. Yes. Why don't you ask one more question, and then we will give the rest of your time to Mr. Gingrey if that is okay.

Mr. BILBRAY. The question is this. There are three major opportunities here. One is nuclear, one is hydroelectric and the other is biofuel, but biofuel needs genetically engineered organisms to make it practical. Wouldn't you agree with that?

Dr. PIZER. It is not really my expertise. I might ask some of the other people to comment on that.

Dr. LEVINE. I tend to agree with that.

Mr. BILBRAY. Yes. So, Mr. Chairman, my point being that the three major options for generating are those that have been actively opposed by people who claim they are supporting the environment. We have to break those taboos, stomp away from the sacred ground, and move into practical applications that the three technologies we are talking, we got to think about when we talk about destroying hydroelectric dams, what is the real big picture here, not just what is the micro picture. We have got to talk about next-generation nuclear, and we got to talk about genetically altered enzymes to be able to produce the biofuels that everybody touts, but when we get to genetically altered, you watch. The people will come out of the woodwork to oppose it, and we have got to find reasons, to find answers rather than always excuses to oppose it.

Chairman GORDON. Thank you.

Mr. BILBRAY. And thank you very much.

Chairman GORDON. Thank you, Mr. Bilbray, and the last word to Mr. Gingrey.

FUTURE IPCC REPORTS

Mr. GINGREY. Definitely not the last word but I thank you, Mr. Chairman.

Would all three of you briefly comment on the thought of maybe having a Working Group IV of the IPCC that was made up of maybe not pure scientists? You have made your case I think pretty well, although my friend on the upper row, Mr. Rohrabacher, would not agree with me on that. But it seems to me that a lot of the discussion that goes on is, well, what do we do about it, and what is the most cost-effective way? Twenty years from now, how much will we be dependent on coal? Dr. Barlett talks about that a lot, and you know, will there be cap and sequestration technology? Hopefully there will be, but it just seems to me that a Working Group IV, if you want to call it that, under the IPCC to say, okay, now, we have got the scientific facts that we have accepted, what is the best, most economical way, what is best for our economy, what is best for our health. What do you think about that?

Dr. PIELKE. I think that doing it via the IPCC might be difficult because it is an international organization and all the international politics involved, but in the United States this could be done right away. And in 1992, the National Academy of Sciences published a massive report called *Policy Options on Climate Change,* a big green volume, and in it they surveyed a whole wide range of options, mainly energy policy, some adaptation. But this committee could very easily motivate such an entity to update this report. What are our options for mitigation, for adaptation? Both narrowly focused on the climate issue but focus broadly on what actions can we take that has a side benefit of reducing emissions. And you could have a report next year, and I think the sooner that sort of thing would be done, the faster you can get input into——

Mr. GINGREY. Yeah, because, let me just interject. I mean, you pick your poison. Would you rather starve to death in 10 years or choke to death in 20, when you get right down to it.

Chairman GORDON. The Chair would be happy to work with Mr. Gingrey in trying to develop something like this.

Let me say this has been a modified type of hearing today. I appreciate the staff, our Members, and the witnesses for their indulgence. This has been important to our continuing basis of knowledge. We have a vote. I am afraid that the attendance would be very poor if we tried to come back again, so we will adjourn, and again, thank you for being here.

[Whereupon, at 12:20 p.m., the Committee was adjourned.]

Appendix:

ANSWERS TO POST-HEARING QUESTIONS

ANSWERS TO POST-HEARING QUESTIONS

Responses by Mark D. Levine, Division Director of the Environmental Energy Technology Division at Lawrence Berkeley Laboratory

Questions submitted by Representative Ralph M. Hall

Q1. In your testimony you state that the building sector needs targeted policies, including regulatory policies, to achieve mitigation goals because a large number of barriers exist in the marketplace to deter investment in energy efficiency. Please give me a few examples of these barriers and explain why you think regulatory policies are the way to overcome them.

A1. Up until appliance efficiency standards were put into place, the energy efficiency of appliances had not increased in years. Manufacturers were not aware of ways to increase efficiency, because they had not explored them. As a result, consumers who may have wanted to obtain efficient appliances could generally not find them in stores. And many customers who were not aware of energy efficiency and thus had no information to know how much high energy-using appliances were costing them.

Appliance efficiency standards changed the situation by requiring all manufacturers to eliminate their most inefficient models. It ensured that the playing field was level, in that all manufacturers had to eliminate inefficient models at the same levels. Later, when the standards brought more efficient models into the market, they continued to have similar effects on all firms; if a more efficient appliance was more expensive for one firm to manufacture it would be for other firms. (As it turned out, the prices of more efficient appliances declined from their less efficient predecessors.)

There are many other examples of market barriers, which have been described with references in the IPCC report. These include:

1. Traditional building design process, in which communications among architects, engineers, and contractors generally precludes execution of measures for the whole buildings
2. Fragmented market structure: many small firms, fragmented knowledge, limited R&D
3. High transaction costs to obtain reliable information about energy savings of energy-efficient equipment (and often to find the equipment)
4. Misplaced incentives and administrative hurdles; e.g., landlords own building but do not pay energy bills
5. Difficulty in obtaining loans because of small project size, high transaction costs and perceived risk.

Questions submitted by Representative Gabrielle Giffords

Q1. As a Representative of a district from Southern Arizona, I am very interested in the potential of solar energy and technologies to contribute to the reduction of emissions of greenhouse gases. I believe that achieving energy independence is the Apollo mission of our generation, and I am pleased that the IPCC Working Group III report acknowledges the significant role that solar energy and technologies can play. Could you please address in detail *how solar energy and technologies can contribute reducing our dependence on fossil fuels both in America and abroad? Please discuss solar technologies expected to be available in 2030 as well.*

A1. Solar energy was placed in the chapter of the IPCC report dealing with energy supply. Thus, I was not part of the overall review of solar energy and this is not my area of expertise.

However, I will share with you some of my views. I agree that there is a significant role for renewable energy. I believe this role will increase substantially with time. Indeed, I am convinced that we need to have very significant increases in renewable energy in many forms in the time frame of one, two, and three decades if we are to have a chance of addressing climate change. Right now, wind energy is commercial in many locations. Unless there is a major breakthrough, it will probably be fifteen to twenty years before solar photovoltaic becomes a very large player. However, thereafter it could be of enormous importance. My personal hope is that we find a way through advanced science and technology to absorb sunlight into woody crops and convert them into fuels in a highly efficient manner. High efficiency is the key; otherwise, very large amounts of land and water will be needed, making the approach impractical.

Q2. As a follow up to my first question, could you address the potential for solar energy and technologies in developing countries and the challenges they might face in deployment of solar?

A2. Because developing countries have the least developed energy infrastructures and will experience the greatest growth in energy demand in the coming decades, the opportunities for renewable energy are great in these countries. A further advantage is that biomass can be gathered at low costs and renewable energy systems can be assembled inexpensively because of low labor costs.

Major challenges are the cost of renewable energy systems—one cannot expect developing countries to pay more than the cost of fossil-based energy—as well as the lack of skilled personnel (both technical and management) and often a very powerful establishment deriving large sums of money from exploitation of fossil fuel.

In spite of these challenges, renewable energy will likely find a large role in developing countries over the coming decades.

Q3. To stabilize greenhouse gas concentrations to a level that will avoid the most dangerous global warming, the costs, according to the Report, may vary from a reduction of three percent GDP to an increase of one percent GDP. The reduction in GDP is deemed to be greater for more stringent stabilization targets. Could you address the issue of cost? Do these numbers take into account the job and economic growth that would result if we invest in a clean future? What role does new and innovative technology play in the figures? Also, what are the costs to the global economy if we do nothing to combat global warming? Can we even truly quantify the costs to the global economy of increased global conflict and decreased food supply, of less water resources and more risks to human health?

A3. As best as I can determine, these costs do assume that new and innovative technology will cone into practice during the period of study. In the technical summary (page 41), it states "Baseline scenarios usually assume significant technological change and diffusion of new and advanced technologies. In mitigation scenarios there is additional technological change 'induced' through various policies and measures." However, it is not reported just how much improvement in technology is to be expected in the different cases, so comparison is difficult.

I am not aware that the numbers take into account job and economic growth resulting from investment in clean energy technologies, as the aggregate models most often assume that such investment is only productive if it lowers the cost of energy.

Most importantly, the numbers cited refer only to the economic costs of reducing emissions of greenhouse gases; they do not include the benefits of avoiding the effects of global climate change. Apparently the integrated analyses of costs and benefits have not been put on a firm enough foundation for the IPCC to quote results on this matter. In my view, you have put your finger on the problem: as you suggest with your question, "we cannot even quantify the costs to the global economy of increased global conflict and decreased food supply, or less water resources and more risks to human health." As a result, IPCC can quote the economic costs of mitigation as estimated by economists but has a difficult time in its literature review of finding quantification of the benefits of mitigation.

ANSWERS TO POST-HEARING QUESTIONS

Responses by William A. Pizer, Fellow at Resources for the Future and Senior Economist at the National Commission on Energy Policy

Questions submitted by Representative Ralph M. Hall

Q1. Some people that advocate for greenhouse gas regulations assert that only with regulations will mitigation technology development occur, but in your testimony you stated that there is little empirical evidence for how technological change will respond to increased demand for emissions reductions. Why don't we have that evidence? What information or research is needed to better understand this assertion?

A1. Most of what we know about the response of technological change to increased demand for emission reductions comes from a limited number of studies. These studies either look at the development of new technology—for example, scrubber patents—in response to policy drivers, or improvements in energy efficiency in response to energy prices. (Popp, 2002; Newell, 1999). A separate line of analysis examines how technology costs fall with expanded production, but it is unclear whether expanded production is causing costs to fall, whether spending on research goes along with production, or whether costs are the same, and expanded productions creates more competition and lower prices to customers Söderholm and Klaasen (2007).

Part of the problem is that we have very poor data on environmental expenditures, on research and development expenditures, and measures of environmental performance. For example, the highly useful "Pollution Abatement Costs Expenditure Survey" collected by the Census Bureau was discontinued in 1994 for budgetary reasons (EPA, 2002). Additional spending on data collection concerning pollution control costs, environmental performance, and research spending, would greatly enhance our understanding of how policy can drive technological improvement (see NRC, 2004).

However, part of the problem is that we are inherently trying to drive the economy in new directions and we cannot completely know the responsiveness of new technologies nor the eventual costs of mitigation efforts to new mitigation efforts. Large scale capture and storage of emissions from coal-fired power plants, advanced nuclear power, and geo-engineered biomass—these are but a few of the technologies that a successful mitigation strategy will depend on. While more research can help us understand the drivers of technological change in the past and likely responses in the future, only pushing the economy in this direction can fully reveal the answers to how well these new technologies will work and at what cost.

That said, twenty years of economic research has revealed one thing—emphasized in the IPCC report: The costs of any mitigation effort will be minimized by flexible market-based policies that create broad demand for new technologies (see Box SPM.3, IPCC WGIII, 2007). Efforts by the government to push particularly promising technologies can be helpful, but only as a complement to increased market demand.

Questions submitted by Representative Gabrielle Giffords

Q1. As a Representative of a district from Southern Arizona, I am very interested in the potential of solar energy and technologies to contribute to the reduction of emissions of greenhouse gases. I believe that achieving energy independence is the Apollo mission of our generation, and I am pleased that the IPCC Working Group III report acknowledges the significant role that solar energy and technologies can play. Could you please address in detail *how solar energy and technologies can contribute reducing our dependence on fossil fuels both in America and abroad? Please discuss solar technologies expected to be available in 2030 as well.*

A1. Overall, solar technologies have a limited potential to displace fossil fuel use in the near- and medium-term out to 2030. Chapter 4 of the IPCC WGIII (2007) report includes an evaluation of the potential contributions of various low-carbon technologies to energy supply in 2030. Section 4.4.3.3 addresses renewable technologies, including solar. It estimates that solar technologies can at maximum contribute 1–2 percent of the total electricity mix worldwide. This percentage is smaller than for other renewable technologies such as hydro, wind, and electricity generated from biomass. The primary reason for this is the projected high costs—between 6 cents–25 cents/kWh in 2030—for solar technologies relative to other low-carbon technologies, as illustrated in Table 4.19: solar technologies are project to have the highest costs, in terms of expense per emissions avoided, of any of the low-carbon technologies discussed in the report.

There are two broad categories of solar technologies for electricity generation. The first is photovoltaic (PV) cells, in which electricity is generated directly. The second is thermal solar power—referred to as concentrating solar power (CSP) plants—in which solar flux is collected, concentrated, and used to heat a working fluid which in turn powers a conventional heat engine (e.g., a steam or gas turbine). PV cells account for the vast majority of current solar generation, with current world peak capacity estimated at 3000–5000 MW. This is located primarily in Germany, Japan, and the United States. Most current installation is in response to subsidies such as installation rebates or feed—in tariffs. About 80 percent of the PV module market is occupied by traditional crystalline silicon cell technology. There are several other technologies which have a small share of the commercial market or are in development which may become more competitive in the future. Thin film solar panels (8–9 percent of the market) typically have lower conversion efficiencies than traditional PV modules, but compete by being less expensive to manufacture. Among the other technologies which are being explored are high efficiency alloy cells, photochemical cells, polymer cells, and multi-layer cells. Most of these are not yet ready for commercialization. Currently, average levelized costs for grid-connected solar power are 17 cents–23 cents/kWh. (This compares with costs of 4–6 cents/kWh for coal- and gas-fired generation.) The U.S. Climate Change Technology Program (CCTP) has a stated goal of reducing these costs to 6 cents/kWh by 2030. A limiting factor for the widespread deployment of solar PV technology could be the cost of silicon, particularly with competition from computing and electronics applications.

There are three main types of CSP plants, categorized by the technology used to concentrate the solar flux: parabolic trough-shaped mirrors, heliostats—mirrors that track the sun—that concentrate flux on a central tower, and parabolic dish-shaped reflectors. The optimal sites for CSP plants are lower latitude locations that receive high levels of direct sunlight, such as the American desert southwest. Currently, there is far less CSP capacity installed—around 350 MWe—than PV capacity. It is also far less dispersed, with almost all current capacity in California, and consists primarily of parabolic troughs. However, there are several new projects underway in 11 countries—including Spain, Israel, and the U.S.—that total over 1400 MW of capacity, and use a wider variety of technologies. The U.S. CCTP has a goal of reducing near-term CSP costs to 9 cents–11 cents/kWh in the Southwest U.S. by 2010, and eventually achieve costs of 3.5 cents–6.2 cents/kWh.

Finally, solar heating and lighting are non-central, distributed technologies that provide the opportunity to reduce demand for centrally-generated energy and reduce peak electricity loads. Passive space heating and cooling relies primarily on building design, including orientation, shading, or placement of windows. Active systems capture solar heat for applications such as domestic hot water, heating of building space, or swimming pool heating. Typical residential hot water systems can provide 40–70 percent of water heating requirements. Although around 1.2 million solar water heating systems are installed in the U.S., the current rate of installation is very low, around 8,000 units per year. Other portions of the world are adopting this technology more rapidly, particularly China, which accounts for 80 percent of global annual installations of solar hot water systems. Worldwide capacity of active solar water heating is around 90 GWth, making solar heating the largest current solar power source.

Q2. As a follow up to my first question, could you address the potential for solar energy and technologies in developing countries and the challenges they might face in deployment of solar?

A2. Solar power does have the potential to make a slightly larger impact in the developing world than in OECD countries. The WGIII report, section 4.4.3.3, projects that while solar is likely to contribute a maximum of one percent of the electricity supply in 2030 for OECD countries, it might amount to two percent in non-OECD countries. Currently about 20 percent of new global PV capacity is being installed in the developing world, primarily in areas that lack access to reliable grid electricity, and that expansion in these countries is rapid, around 30 percent annually. A recent book (Barnes, 2007) includes case studies of how several countries, including Tunisia and Mexico, successfully used PV power as one part of a strategy to increase electrification in rural areas, relying on PV as a complementary strategy for isolated users who could not access the grid. The high cost of PV power, however, meant that these policies had to be heavily subsidized. Expansion of solar power in developing countries will continue to rely on subsidies from governmental and non-governmental organizations and policies.

Q3. To stabilize greenhouse gas concentrations to a level that will avoid the most dangerous global warming, the costs, according to the Report, may vary from a reduction of three percent GDP to an increase of one percent GDP. The reduction in GDP is deemed to be greater for more stringent stabilization targets. Could you address the issue of cost? Do these numbers take into account the job and economic growth that would result if we invest in a clean future? What role does new and innovative technology play in the figures? Also, what are the costs to the global economy of we do nothing to combat global warming? Can we even truly quantify the costs to the global economy of increased global conflict and decreased food supply, of less water resources and more risks to human health?

A3. As indicated in my written testimony, I tend to be wary of the low-end cost estimates contained in the IPCC report—suggesting a change in global GDP of between +0.6 and -3 percent (Table SPM 4, IPCC WGIII, 2007). The estimates of gains in global GDP hinge on two assumptions: (1) there are significant inefficiencies in the existing economy; and (2) that government policies will fix these inefficiencies and yield a gain. While certainly (1) is true, and (2) is likely true in some limited cases—mainly surrounding energy efficiency and basic research—it seems unlikely that both are true at a sufficiently large scale to make a difference in general cost studies.

The argument that job and economic growth can occur from an innovative and clean future ignores the strong evidence that large volumes of clean energy will cost more than ordinary energy. The best example is carbon capture and storage, whereby CO_2 emissions from a coal-fired power plant are captured and stored underground-perhaps the most important technology we are counting on to mitigate climate change. The cost of capturing and storing CO_2 will always be an additional cost relative to operating a coal-fired power plant without capture and storage. In this way, clean energy clearly costs more than ordinary energy.

This is not to say that investing in clean energy technologies now will not cut costs in the future, nor give the U.S. some amount of a international competitive advantage as future energy trends evolve towards cleaner sources. Rather, reducing emissions will still cost real resources relative to not reducing emissions.

All of that said, I do believe that we can make significant reductions in emissions at costs of less than one percent of global world product, and probably achieve the most aggressive targets at three percent—assuming we can achieve global participation and enact efficient policies. In my mind, these are costs worth enduring.

There have been a variety of efforts to quantify the costs of inactions, summarized in section 20.6 of the IPCC WGII (2007) report. These estimates tend to be less compelling than the cost studies because they are even more uncertain and hinge on many subjective parameters—most notably the rate of "return" required on climate change investments (also referred to as the discount rate). While Stern (2006) suggested damages equivalent to five percent of GDP, this was roundly criticized by leading economists, primarily on the based on the discount rate assumptions (Dasgupta, 2007; Nordhaus, 2007; Mendlesohn, 2007; Tol and Yohe, 2006).

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ANSWERS TO POST-HEARING QUESTIONS

Responses by Steven E. Plotkin, Transportation Energy Analyst with the Center of Transportation Research at the Argonne National Laboratory

Questions submitted by Representative Ralph M. Hall

Q1. In your testimony you state that technologies are available today to sharply reduce greenhouse gas emissions from the transport sector, but strong government actions will be needed for those technologies to reach their full potential. Please elaborate on this point: Specifically what technologies are you talking about? If the technologies are available today, why is government action needed? What are the major technical hurdles to making these technologies available? What are the major (if any) societal or policy hurdles?

A1. Your first question concerns technologies available today to reduce greenhouse gas emissions from the transport sector. In my testimony, I identified many of these technologies. Some of the most promising technologies for light-duty vehicles are:

- **Direct injection turbo-charged diesel engines.** These engines represent about half of the engines currently being sold in Europe, but few are sold in the U.S. except in some light truck segments of the market. They can reduce GHG emissions by about 20 percent compared to current gasoline engines.
- **Direct injection gasoline engines, in both turbo-charged and naturally-aspirated form.** Growing numbers of manufacturers (e.g., Audi, Mazda, GM, Toyota, BMW) are offering these in the U.S., but presently only in a few models. They should become more common in the future.
- **Hybrid electric drivetrains ranging from simple stop-start systems to full hybrids (e.g., Toyota's Prius).**
- **6, 7, and 8 speed automatic transmissions.** Currently available only on luxury models, they will migrate to the rest of the fleet.
- **Improvements in aerodynamic performance.** Sharp improvements have recently been obtained in the crossover SUV segment of the market, and there is significant opportunity across the fleet.
- **Low rolling resistance tires.** A key issue here is the difficulty of obtaining these in the aftermarket; this was addressed recently by the National Academy of Sciences.
- **Weight reduction through new materials and improved design.** A 10 percent reduction in vehicle weight can translate into a 6–7 percent improvement in fuel economy if engine power is reduced to maintain the same performance.
- **A wide variety of engine improvements, including more sophisticated valve controls, engine friction reduction, variable air intake systems, high pressure fuel injection systems, etc.**
- **Electric power steering and air conditioning.**
- **Higher efficiency accessories and measures to reduce vehicle heating and cooling loads (e.g., window films to block solar input into the cabin).**

There are also many technologies currently in development that have an excellent chance of technical and market success. Industry analysts believe, for example, that gasoline engines will gradually gain the ability to use thermodynamic cycles that are more efficient than the current Otto cycle. Plug-in hybrid vehicles may also play an important role if battery development succeeds in providing less expensive and more robust high-energy batteries. Biofuels, and in particular ethanol or other fuels from cellulose, can play a significant role in replacing oil and reducing GHG emissions, but only if production costs can be reduced substantially. And eventually, hydrogen fuel cell vehicles may become commercially feasible, although there remain important barriers in fuel cell cost, onboard hydrogen storage cost and capacity, and the need to simultaneously develop a fuels infrastructure and vehicle production capacity.

Many of the above technologies will gain market share without government intervention, and some have already been helped by government economic incentives—hybrids, for example, have been helped by generous federal tax credits. However, in the absence of further government action, improvement in U.S. light duty vehicle fuel economy may be quite disappointing. The primary reason for this prediction is that U.S. consumers behave as if they do not place a high value on fuel economy performance when purchasing new vehicles. Also, many vehicle purchasers apparently place a high value on vehicle features that directly conflict with fuel efficiency—particularly engine power and acceleration performance. In my testimony, I noted that between 1987 and 2006 the U.S. new light duty vehicle fleet became 27 percent heavier and 30 percent faster in 0–60 mph acceleration time, and actually declined in fuel efficiency despite the introduction and widespread penetration of a wide array of fuel efficiency technologies. Although high gasoline prices might shift this trend somewhat in the future, I am relatively pessimistic that the market alone will produce important gains in fleet fuel economy. Instead, I expect to see many of the potential gains of these technologies used instead to improve vehicle performance and increase other vehicle amenities, and I also expect that some of the technologies will fail to gain nearly as much market share as would occur if fuel economy were more highly valued.

The obvious question that arises from this narrative is, "Why should Congress act to override market forces?" Historically, Congress has intervened in markets when it determines that public values override private incentives and/or that markets are operating inefficiently. For example, Congress enacted vehicle emission requirements when it determined that private decisions about the benefits of emission controls did not protect public health. And partly because many purchasers of appliances are home builders and rental building landlords who do not pay for the cost of operating the appliances during their lifetime, Congress enacted legislation requiring the Department of Energy to set standards for appliance energy efficiency. Although purchasers of light-duty vehicles and other energy-using equipment will gain personal benefits from higher fuel efficiency, in the form of reduced energy bills, they generally take no account of the societal costs of energy use—in particular, emissions of greenhouse gases and their impact on climate change, and the energy security costs of oil use. Further, many analyses of the costs and benefits of automobile fuel efficiency technologies have concluded that the net *personal benefits*—fuel savings minus higher vehicle costs—tend to be relatively small over a range of fuel savings options. Combined with consumers' tendency to value only the first few years of fuel savings, this discourages manufacturers from taking market risks in pushing fuel economy.

One obvious way Congress could address this issue is with new, more stringent fuel economy standards. Automakers opposing new standards have argued that they will greatly increase their market risks because consumers won't want to purchase the more efficient but more costly vehicles that will result. Consumers' response to the emission standards mentioned above—they were willing to continue to purchase new vehicles with expensive emission controls despite industry fears—provides a counter-argument. Using emission standards as an example, I would argue that new fuel economy standards can be successful if the following criteria are met:

- Consumers must believe that the standards make sense, that is, that they promote a real societal benefit (from decreased GHG emissions and lower oil imports);
- The new standards must be technically achievable at reasonable cost and must give automakers sufficient time to redesign their fleets; a starting point for negotiations about "reasonable cost" might be the breakeven point between higher vehicle cost and lower fuel cost, with or without "externalities" accounted for in fuel cost; and
- The structure of the standards must be designed to spread the burden equitably among different automakers, to minimize market risk; the current NHTSA design for new light truck standards (fuel economy targets based on vehicle "footprint") is a good starting point for this.

Q2. In your testimony you state that the greatest potential impact on greenhouse gas emission reduction in the transport sector lies in the developing world. If the U.S. adopted many of the transport technologies and policies you discussed but the developing world did not, would the U.S. actions it have a discernible influence on greenhouse gas levels? If so, what magnitude decrease could be achieved? How would that number change if the developing world did participate?

A2. In your second question, you begin by saying that I claimed in my testimony that "the greatest potential impact on greenhouse gas emission reduction in the transport sector lies in the developing world." I would like to repeat what I said in my testimony:

> A combination of careful urban planning and promotion of efficient public transport and walking and cycling can have a profound longer-term positive impact on GHG emissions from urban transport as well as on the livability of cities. Although the greatest impacts will be in the developing world whose cities and transport systems are undergoing rapid transformation, important positive impacts can occur in the industrialized nations as well.

In other words, my statement about the differential potentials in the developed and developing world referred only to the potential of urban planning and alternatives to private vehicles. The role of advanced technology may well be more important in the developed world than in the developing world. One possible exception to this is the potential to introduce a gaseous vehicle fuel—the lack of an established gasoline refueling infrastructure in developing countries might offer some advantage here, although that might be overwhelmed by other considerations such as availability of skilled construction labor.

In my view, it is unlikely that the U.S. would adopt multiple new transport technologies and policies without much of the rest of the world doing so also, because the technologies are fungible and because much of the rest of the world is already moving to promote improved efficiency in their light-duty fleets. In particular, Europe and Japan have much higher transport fuel prices than those in the U.S. but also have new fuel economy standards that are considerably more stringent than we have. And China, the developing nation with the fastest growing fleet of private vehicles, also has enacted standards that are quite stringent for larger vehicles.

It is still possible to get a sense for what might happen if the U.S., or the OECD nations, acted alone or together with the rest of the world in curbing transport GHG emissions by examining the current and expected shares of transport emissions and energy use in these regions. In the year 2002, the U.S. and Canada accounted for about 39 percent of total world transport energy use and GHG emissions, and the OECD nations (which include the U.S. and Canada) accounted for 68 percent. By 2030, the International Energy Agency's 2004 International Energy Outlook expected the U.S. and Canada share to decline to 32 percent, and that of the OECD nations to decline to about 55 percent. Consequently, if the U.S. acted alone, it would essentially leave about two-thirds of world transport emissions untouched; if the developed nations of the OECD acted alone, without the developing nations and the economies of the former USSR that would leave about 40 percent of the world transport emissions untouched.

In the IPCC analysis, which focused on light-duty vehicles, about half of the 2030 reductions in GHG emissions (from a "business as usual" case) achieved by an "efficiency strategy" occurred in the United States, and about 70 percent occurred in the OECD countries. The U.S.'s large share of reductions results from two factors—the very high driving rates for U.S. vehicles (which improves the economic viability of new technologies), and the low expected fuel economy levels for the U.S. fleet in the "business as usual" case, which leaves more room for improvement. In other words, for this one analysis, the effect of the U.S. "going it alone" would mean that the total GHG emissions reductions achieved worldwide for the light-duty vehicle sector would be cut in half compared to a worldwide strategy.

Questions submitted by Representative Gabrielle Giffords

Q1. As a Representative of a district from Southern Arizona, I am very interested in the potential of solar energy and technologies to contribute to the reduction of emissions of greenhouse gases. I believe that achieving energy independence is the Apollo mission of our generation, and I am pleased that the IPCC Working Group III report acknowledges the significant role that solar energy and technologies can play. Could you please address in detail *how solar energy and technologies can contribute reducing our dependence on fossil fuels both in America and abroad? Please discuss solar technologies expected to be available in 2030 as well.*

Q2. As a follow up to my first question, could you address the potential for solar energy and technologies in developing countries and the challenges they might face in deployment of solar?

Q3. To stabilize greenhouse gas concentrations to a level that will avoid the most dangerous global warming, the costs, according to the Report, may vary from a reduction of three percent GDP to an increase of one percent GDP. The reduction in GDP is deemed to be greater for more stringent stabilization targets. Could you address the issue of cost? Do these numbers take into account the job and economic growth that would result if we invest in a clean future? What role *does new and innovative technology play in the figures? Also, what are the costs to the global economy of we do nothing to combat global warming? Can we even truly quantify the costs to the global economy of increased global conflict and decreased food supply, of less water resources and more risks to human health?*

A1, 2, 3. Congresswoman Giffords' questions focus on solar energy and broadly on stability costs and benefits. I have no expertise to deal with her first two questions, about the role of solar energy, and only limited expertise in dealing with the third question, about costs. I will only make a few comments on this last question.

The first part of the question asks whether the mitigation cost numbers take into account the job and economic growth that would result if we invest in a clean future. Although some mitigation analyses identified in the literature—particularly those that use sophisticated economic models—will capture such effects to some extent, the analysis used in the transport sector did not use an economic model and would not have captured economic growth and jobs impacts.

The question then asks about the role of new and innovative technology in the cost figures. The analyses and models used to quantify the costs and GHG emissions reductions of various mitigation strategies have limited ability to capture the role of new and innovative technologies, especially over longer time frames. Those technologies that have begun development generally have highly uncertain future costs and performance, and their likely future market penetration also is highly uncertain. The instigation of incentives to reduce emissions eventually will yield new but as yet unidentified technologies, but no analysis or model can properly account for these technologies. At best, analyses and models can assume rates of improvement in the energy efficiency of core services and industries, based on historical experience.

A second part of the question asks whether we can quantify the costs to the global economy if we do nothing to combat global warming. The mitigation report did not address this issue, and the issue lies outside my area of expertise.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Roger A. Pielke, Jr., Professor of Environmental Studies Program at the University of Colorado and Director of the Center for Science and Technological Policy Research

Questions submitted by Representative Gabrielle Giffords

Q1. As a Representative of a district from Southern Arizona, I am very interested in the potential of solar energy and technologies to contribute to the reduction of emissions of greenhouse gases. I believe that achieving energy independence is the Apollo mission of our generation, and I am pleased that the IPCC Working Group III report acknowledges the significant role that solar energy and technologies can play. Could you please address in detail *how solar energy and technologies can contribute reducing our dependence on fossil fuels both in America and abroad? Please discuss solar technologies expected to be available in 2030 as well.*

A1. I am not an expert in solar energy technology.

Q2. As a follow up to my first question, could you address the potential for solar energy and technologies in developing countries and the challenges they might face in deployment of solar?

A2. As above in #1.

Q3. To stabilize greenhouse gas concentrations to a level that will avoid the most dangerous global warming, the costs, according to the Report, may vary from a reduction of three percent GDP to an increase of one percent GDP. The reduction in GDP is deemed to be greater for more stringent stabilization targets. Could you address the issue of cost? Do these numbers take into account the job and economic growth that would result if we invest in a clean future? What role does new and innovative technology play in the figures? Also, what are the costs to the global economy of we do nothing to combat global warming? Can we even truly quantify the costs to the global economy of increased global conflict and decreased food supply, of less water resources and more risks to human health?

A3. The IPCC estimates for the future costs of stabilization depend a great deal upon assumptions used in the so-called "Integrated Assessment" models that are used as the basis for the scenarios employed by the IPCC (the "SRES scenarios). Each of these scenarios assumes that spontaneous technological innovation (i.e., without implementation of climate-related energy policies) will account for an enormous reduction in future emissions, as compared to scenarios with no technological innovation (note that the IPCC discusses this on pp. 218–221 of Chapter 3 in its Working Group III report, see especially Figure 3.33 which shows this reduction).

One question that has received insufficient attention is whether or not the assumptions by the IPCC of such automatic emissions reductions via spontaneous technological innovation are in fact sound. If such technological innovation does indeed occur spontaneously, then the marginal costs of stabilization of greenhouse gases will be much smaller than otherwise. Rather than assume such technological innovation, it may be appropriate for Congress to consider ensuring that it occurs through an aggressive investment strategy that has benefits not simply for climate, but for air pollution, reduced reliance on foreign energy sources, job creation, and economic competitiveness.